DTIC FILE COPY

NWC TP 6808

Geothermal Resource Evaluation at Naval Air Station Fallon, Nevada

by
Allan M. Katzenstein
and
Steven C. Bjornstad
Public Works Department

AUGUST 1987

AD-A199 416

NAVAL WEAPONS CENTER
CHINA LAKE, CA 93555-6001

Approved for public release; distribution is unlimited.

DTIC
ELECTE
DEC 1 4 1987
S E D

87 12 9 188

Naval Weapons Center

FOREWORD

The work described in this report was performed by the Naval Weapons Center, China Lake, Calif., under Naval Civil Engineering Laboratory Project No. 63724.RO829.804. This report is a follow-up on a series of geothermal exploration programs at Naval Air Station Fallon, Nev., and presents an updated evaluation of the geothermal potential of that area. The work described was carried out during fiscal years 1985 and 1986.

The report has been reviewed for technical accuracy by C. F. Austin.

Approved by
R. M. CUGOWSKI
Capt., CEC, USN
Public Works Officer
29 July 1987

Under authority of
J. A. BURT
Capt., USN
Commander

Released for publication by
G. R. SCHIEFER
Technical Director

NWC Technical Publication 6808

Published by . . . . Technical Information Department
Collation . . . . Cover, 28 leaves
First printing . . . . 140 copies

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD-A191416

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Public release; distribution is unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NWC TP 6808	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Weapons Center 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State, and ZIP Code) China Lake, CA 93555-6001	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING/SPONSORING ORGANIZATION Naval Civil Engineering Laboratory 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Port Hueneme, CA 93042	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO · PROJECT NO · TASK NO · WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
Geothermal Resource Evaluation at Naval Air Station Fallon, Nevada

12 PERSONAL AUTHOR(S)
Katzenstein, A. M.; Bjornstad, S. C.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
FINAL	FROM 85 Jun TO 86 Aug	1987, August	53

16 SUPPLEMENTARY NOTATION

17 COSATI CODES		
FIELD	GROUP	SUB-GROUP
08	04, 07	

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Aquifer; Chip Samples; Convection Cell, Core Samples, Geochemistry, Geology, Geophysics, Geothermal Resource, Heat Flow, Lithology Log, Observation Hole, Thermal Gradient, Reservoir Characteristics.

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

(U) During the summer of 1986, Fallon Observation Hole 2 (FOH-2) was drilled in the southeast corner of Naval Air Station (NAS) Fallon, Nevada, to provide additional information on the geothermal resource at that installation. The hole penetrated 2223 feet of sediments followed by 2262 feet of volcanics. FOH-2, which bottomed in volcanics, had a total hole thermal gradient of 5.7°F/100 feet, with a bottom hole temperature of approximately 311°F. This information, coupled with geoscientific data gathered throughout the last 8 years, strongly suggests that the southeastern corner of NAS Fallon is underlain by a moderate- to high-temperature geothermal resource at an exploitable depth.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Allan M. Katzenstein	22b TELEPHONE (Include Area Code) 619-939-3411 Ext. 471 · 22c OFFICE SYMBOL NWC Code 2661

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Accession For
NTIS GRA&I X
DTIC TAB
Unannounced
Justification

By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

DTIC COPY INSPECTED 6

CONTENTS

ACKNOWLEDGMENT

Successful completion of this phase of the Fallon geothermal exploration project depended on the cooperation and coordination of several individuals from three separate U.S. Government agencies. Excellent base support and local coordination was provided at NAS Fallon by LCdr. John Berriman, Public Works Officer; and Jim Regan, Deputy Public Works Officer. Contracting of the drilling company would not have been possible without the efforts of two people from the U.S. Department of Energy: John Crawford, Project Manager, Fossil, Geothermal, and Solar Division; and Jeff Mark, Contract Specialist, Contract Management Division. Electric and thermal-gradient well logging was provided by Fred Grubb, U.S. Geologic Survey, Menlo Park, Calif.; and heat flow capacity determinations on the core samples were provided by John Sass, U.S. Geologic Survey, Flagstaff, Ariz.

We also appreciate the assistance of Carole Anderson, Lucy Carson, Gene Edwards, and BUCS B. J. Harger II of the Geothermal Program Office for their part in the 24 hours a day, 7 days a week job of "sitting the drilling rig" while Fallon Observation Hole 2 was being drilled.

INTRODUCTION

This is the third major technical report that the Geothermal Program Office at the Naval Weapons Center has published concerning the geothermal exploration program at Naval Air Station (NAS) Fallon, Nevada. Results of the two previous publications by Bruce (1980) and by Katzenstein and Danti (1982) are discussed in detail in this report. In addition, some information is presented from the exploration efforts of the Helioscience General Joint Venture at NAS Fallon.

Mainside in this report refers to the area containing the airfield, lodging, and administration buildings. NAS Fallon in this report refers to the entire Mainside plus the outlying bombing ranges.

The main purpose of this report is to present the results of drilling a 4485-foot core hole in the southeastern corner of Mainside. This information, coupled with what was already known from previous exploration efforts, provided us with the opportunity to refine our interpretations of the geothermal system present beneath Mainside. Although some important data remain to be gathered about the resource, such as fluid availability and dynamics, we believe that a geothermal system is present in the southeastern corner of Mainside, that it is exploitable, and that it could be used to make Mainside energy self-sufficient.

To provide continuity with previous studies, information is reported in the British system of units (foot, pound, second) and degrees Fahrenheit.

GEOGRAPHY AND PHYSIOGRAPHIC SETTING

Mainside lies approximately 65 miles east of Reno in southwestern Churchill County, Nev., adjacent to the town of Fallon (Figure 1). Fallon, the county seat, is at the intersection of two major U.S. Highways, Highway 50, running east and west, and Highway 95, running north and south. A branch line connects Fallon with the main line of the Southern Pacific Railroad in the northwest part of the county.

The northern section of the Basin and Range physiographic province, the Great Basin, consists typically of linear, north- and south-trending mountains separated by broad desert valleys, resulting in a number of independent internal drainage districts or closed basins (Hunt, 1979). NAS Fallon lies within the Lahontan Basin subsection, the western portion of the Great Basin section adjacent to the Sierra Nevada. Lakes, playas, and alluvial plains make up 35 to 40% of the subsection, with the remainder being mountains and alluvial gravel fans. Pyramid Lake, Lake Winnemucca, Walker Lake, and the Carson Sink are all remnants of the Pleistocene Lake Lahontan.

Churchill County is an area of generally low annual precipitation (slightly over 5 inches, Naval Weather Service), high summer temperatures, and moderate winters. The western half of the county is an area of low relief characterized by large playas and salt flats, surrounded by low mountains of less than 1200 feet of relief. The low mountains are generally bare of trees and support a sparse cover of brush and grass. The playa lakes and salt flats occupy the low parts of the valleys, the largest of these being the Carson Sink. The Sink is approximately 20 miles in diameter and is the terminus of two major rivers in Nevada, the Humboldt coming in from the northeast, and the Carson from the southwest.

Mainside is in the Lahontan Valley, which is the elevated southern end of the Carson Sink. Mainside NAS Fallon is surrounded by irrigated farm and ranch land. Potable water is provided by wells drilled into shallow aquifers with irrigation water coming totally from the Carson River. The excess irrigation water runs into nearby swamps and into Carson Sink.

GEOLOGIC HISTORY

PRE-CENOZOIC PERIOD

The rocks that make up the pre-Cenozoic basement in the Fallon area evidence several cycles of tectonic development. The Antler, Sonoran, Nevadan, Sevier, and Larimide orogenies, preceded and separated by periods of relatively quiet basin formation and sedimentation, occurred over a long period of time, from the late Devonian period through the end of the Paleocene period. These orogenies are expressed by deformation, general east to southeast thrusting of western rocks over eastern, the melting of deep crustal and subcrustal rocks accompanied by the emplacement of intrusives, and volcanic and hydrothermal activity.

The primary effect of this tectonic activity that is important in an evaluation of the potential for geothermal resources at Fallon is that the resulting "basement" is not homogeneous; there has been extensive opportunity for the complex overprinting of major structural lineations. These older lineations in turn affect the patterns of more recent tectonic activity, including the configuration of the present geothermal systems of the region.

CENOZOIC PERIOD

Cenozoic tectonics is dominated by the basin and range structure of generally subparallel linear mountain chains separated by broad alluvium-filled valleys, e.g., basin-range faulting that traditionally has been considered characterized by extensive, young, normal fault movements. Much of the geoscientific work done in the Basin and Range province has assumed the necessity of an extensional regime during this period to account for the present structure, beginning with Gilbert (1872) and repeated extensively up through recent studies that include Dickinson and Snyder (1979), Zoback and Thompson (1978), Cross and Pilger (1978), and many others. However, there is evidence of reverse movement on previous thrust faults in the Basin and Range province. Recent deep drilling and three-dimensional studies indicate increasing evidence for widespread extensional movement that is centered on and overlying thrust fault systems and is related to low-angle spreading of a shallow nature*. These newer concepts of exotic terrains are, in the words of one author, resulting in the complete rewriting of the textbooks (D. R. Lageson, 1982).

*Personal communication between M. Erskin, Jr., and C. F. Austin, 1986.

Additionally, rocks of Miocene to middle Pliocene age, exposed at several sites in Churchill County, show evidence of deformation by compressional forces (folding and reverse faulting). These rocks are lacustrine and fluvial sediments interlayered with basaltic to rhyolitic volcanics. Willden (1969) felt that these structures indicate that regional crustal shortening was still operative in this area as late as middle Pliocene time, suggesting that the Pliocene zone of intense thrusting (Eardly, 1951) that extends north from the Garlock Fault in east-central California probably continued into the Fallon region.

CENOZOIC VOLCANIC ACTIVITY

The Fallon area has seen fairly continuous volcanic activity since the Mesozoic period, with most of the activity occurring prior to the beginning of the Basin and Range activity. A small amount of activity has been identified for the period of 43 to 34 million years before the present (MYBP). These are flows and breccias of andesitic and intermediate composition (Stewart and Carlson, 1976).

A distinct swath of volcanic activity approximately 160 miles wide and trending generally west-northwest was present in Nevada in the period of 34 to 17 MYBP. This activity includes two large east-west elongated, fault-bounded troughs that were located in the central part of the Basin and Range province during the Oligocene and early Miocene periods. These troughs were sites of intense rhyolitic to andesitic volcanism and coeval faulting. The orientation and age of these volcano-tectonic features fit with a regional pattern of south-southwest migration of calc-alkalic volcanism that lasted from about 42 to 18 MYBP (Burke and McKee, 1979). The Carson Sink covers the apparent western margin of the southern volcano-tectonic trough (Figure 2).

A distinct change in the character of volcanic activity in Nevada (and in the Fallon area in particular) occurred approximately 17 MYBP and continued until about 6 MYBP. This period was marked by the widespread eruption of mafic lavas, mostly basalt and bimodal assemblages of basalt and rhyolite. Rocks of the Chloropagus, Desert Peak, and Bunejug Formations found in the mountains and hills west and south of the Carson Sink were deposited during this period.

Volcanic activity has been sparce and scattered in Nevada from 6 MYBP to the present; a few small occurrences of Quaternary age outcrop in the Fallon area, including the Rattlesnake Hill vent and a maar at Soda Lakes.

REGIONAL GEOTHERMAL

There are four areas around Mainside Fallon that have known geothermal resources and have been studied to some extent: (1) Desert Peak, (2) Soda Lake, (3) Stillwater, and (4) Salt Wells (Figure 3). The following is a summary of some of the known geothermal characteristics of each resource.

DESERT PEAK

Desert Peak is located approximately 30 miles northwest of Mainside and several miles east of Brady Hot Springs. Presently, there is a 9-megawatt geothermal power plant at Desert Peak operated by Chevron Resources. The power plant takes advantage of an average flow rate of 500,000 lb/hr per well total mass flow with an average wellhead temperature of 326°F; average resource temperature is 400°F (Cerini and others, 1984).

Benoit and others (1982) provided a comprehensive study of Desert Peak. Most of the following discussion on the discovery and geology is paraphrased from that report. The geothermal field at Desert Peak was a blind discovery–located almost wholly by shallow temperature holes, stratigraphic tests, and the resulting temperature patterns. Prior to the drilling of temperature gradient holes, Brady Hot Springs, 4 miles to the west, was the only geologic evidence for a possible geothermal field in the area. The geophysics attempted at Desert Peak provided ambiguous results, while infrared imagery processed in 1978 revealed no surface heat anomalies.

Geologic mapping completed after the discovery of the geothermal field indicates that this field occurs at the intersection of two structural trends. Apparently, the reservoir has been structurally uplifted along high-angle Tertiary faults to depths shallow enough to permit detection and economic exploitation. The geothermal reservoir is contained beneath Tertiary volcanic rocks in fractured pre-Tertiary basement rocks whose stratigraphy and structure are not well known. The thick sequence of Tertiary volcanic rock acts as the caprock to the reservoir.

Using the results of drilling at Desert Peak, the estimated depth to 400°F arbitrarily indicates the configuration of the top of the reservoir. The configuration to the top of the producing zones (or fractures) within the reservoir cannot be contoured because of lack of data. Benoit and others (1982) reported that only two wells (B21-1 and B21-2) provided reliable data about the top of the producing zone. The top of the producing zone in Well B21-1 is at 3638 feet, 1908 feet lower than the top of the reservoir (400°F isotherm) and 500 feet below the top of the pre-Tertiary rocks. The top of the producing zone in Well B21-2 is at 2871 feet, 331 feet lower than the top of the reservoir and a mere 63 feet below the top of the pre-Tertiary rocks. The depth of the producing zone in a third well (B21-3) was not known in 1982, but the top of the reservoir was 975 feet below the top of the pre-Tertiary rocks.

The source of heat at Desert Peak is not known. Information available in 1982 did not support the interpretation that a shallow magma chamber was present below or near the Desert Peak area. Heat flow outside the Desert Peak area is near the average for the Basin and Range physiographic province, implying that thermal waters must circulate (or convect) to depths greater than 8200 feet to attain the observed temperatures at Desert Peak (Yeamans, 1983). Movement of fluid within the geothermal reservoir is probably a consequence of the intersection of Tertiary faults and pre-Tertiary basement tectonic features.

SODA LAKE

Soda Lake is 15 miles northwest of Mainside. Although this site has been studied extensively, much of the information remains proprietary. However, it is believed that the Soda Lake thermal anomaly is a plume of hot water rising along a northeast trending structure located just north of Soda Lake. Using seismic data, this structure has been interpreted as a narrow graben by Hill and others (1979). Thermal gradient holes and deep test wells drilled within the thermal

anomaly indicate a reservoir temperature in excess of 368°F and, using results of geochemical analysis of recovered fluids from a permeable zone at 1000 feet in Soda Lake Well 1-29 (a Phillips Petroleum well), probably in excess of 400°F. The hottest reported temperature is 399°F in Well 84-83 (Benoit and Butler, 1983). However, the reservoir is not yet well defined, and it is not known if the fluids recovered are from producing zones within the reservoir or outflow zones leaking from a central reservoir located some lateral distance away. Hill and others (1979) believe the possible reservoir types are (1) a fractured reservoir in the thick (late) Tertiary volcanic sequence, (2) intervolcanic sediments in the volcanic sequence, (3) a fractured reservoir within underlying Mio-Oligocene acid tuffs and lavas, or (4) a fractured reservoir in the pre-Tertiary basement complex (analogous to the Desert Peak thermal anomaly). The heat source has not been determined.

STILLWATER

Even less information has been published on the Stillwater thermal anomaly located approximately 10 miles northeast of Mainside. Based on well completion cards of the Petroleum Information Corp., it is known that temperatures near 335°F were recorded in the De Braga No. 2 Well (a Union Oil of Calif. well) at a depth of 6920 feet. The well flowed 150,000 lb/hr wet steam in the interval from 2724 to 6940 feet, with a wellhead temperature of 252°F during a 24-hour test. The well bottomed at 6946 feet in pre-Lake Lahontan Tertiary rocks. To the west, the Richard Weishaupt No. 1 Well (another Union Oil of Calif. well) had a maximum temperature of 353°F at 9950 feet but encountered no fluids while drilling. The hole bottomed at 10,014 feet in felsic volcanics. The hole was nitrogen stimulated but apparently did not flow (Edmiston and Benoit, 1984).

Recently, Trans-Pacific Geothermal Corporation (TGC), Oakland, Calif., acquired all Union Oil of Calif. geothermal leases in the Stillwater area. As of 1986, TGC's plans consisted of building a 1- to 2-megawatt power plant to be installed and on-line by the end of the first quarter of 1987, with an additional 8 to 9 megawatts to be brought up by the end of 1987 (*Geothermal Hot Line*, 1986). TGC will be using fluids from the reservoir with temperatures ranging from 320 to 335°F.

Stillwater is stratigraphically similar to the Soda Lake thermal anomaly but aligns structurally with the Salt Wells anomaly located 12 miles to the south of Stillwater. Edmiston and Benoit (1984) believe that Stillwater and Salt Wells are linked by an active fault system that has some control of the hydrothermal circulation at both anomalies.

SALT WELLS

In the fall of 1985, Anadarko Petroleum Corp., Houston, announced a geothermal discovery in the Salt Wells area, 10 miles southeast of Mainside (Geothermal Resources Council, 1985). The 700-foot well was pumped at a maximum sustained rate of 1300 gallons of hot water per minute during a 4-day test. Water temperature was reported to be from 269 to 285°F. In 1980, Anadarko Petroleum reported on the 14-36 Federal Well, which bottomed at 8500 feet in a quartz monzonite (Edmiston and Benoit, 1984). The well produced more than 150,000 lb/hr of water from fractures at 6100 and 6750 feet, with a maximum temperature in this interval of 320°F. Deeper fractures were less productive but had slightly higher temperatures (Edmiston and Benoit, 1984).

HISTORY OF THE NAVY'S EXPLORATION EFFORTS AT NAS FALLON

THE BRUCE REPORT–1980

The NAS Fallon exploration project was implemented in the late 1970s by the Geothermal Utilization Division (now the Geothermal Program Office), Naval Weapons Center, China Lake, Calif., to assess the geothermal potential of selected areas of NAS Fallon. At that time, the exploration effort included Mainside and the outlying bombing ranges of Bravo 16, 17, 19, and 20. The exploration effort at Bravo 17 and 20 was dropped after it was determined that the remote location would preclude practical or profitable Navy geothermal development. Mercury studies and some thermal gradient drilling, as reported by Bruce (1980), were then accomplished on Mainside and Bravo 16 and 19 as follows.

There is no surface manifestation of the presence of a geothermal resource at NAS Fallon. However, Mainside is located a few miles north of a hot artesian well having a reported bottom hole temperature of 170°F (Figure 4, Well 6). Bruce was able to estimate a resource temperature of 399°F using the Na-K-Ca geothermometer on results of a chemical analysis of fluids in this well. The Navy drilled four thermal gradient (TG) holes near the southeast corner of Mainside (Figure 4, Holes TG 23 through TG 26) in an attempt to delineate any thermal anomaly beneath Mainside associated with the heat found in Well 6. Resultant gradients ranged from 5.3 to approximately 13°F/100 feet (9.7 to 23.7°C/100 meters). To further delineate the emerging thermal anomaly beneath NAS Fallon, trace mercury studies were attempted at Mainside and also at Bravo 16 and 19. Results of the mercury study on Mainside indicated a possibility of substantial geothermal fluids at an exploitable depth, based on the presence of high mercury anomalies at the surface (Figure 5). The mercury pattern that emerged indicated that the southeastern portion of Mainside was probably cut by three different trending features (northeast, north-northwest, and northwest) paralleling the main tectonic trends of western Nevada (see Figure 3). Such a pattern of faults could allow for a fractured subsurface, which would provide adequate porosity to form a reservoir while allowing conduits for escaping geothermal fluids.

Bruce (1980) concluded that the southern portion shows the best potential for geothermal development at Mainside. "Here," he wrote, "a high mercury anomaly exists, paralleling a probable buried fault (lineament), and the area also has a high geothermal gradient (up to 9.5°F/100 feet). This could indicate a 300°F resource may exist at depths of 2,500 to 3,000 feet."

A study of Bravo 19 indicated lower concentrations of mercury were present in that area than on Mainside, probably due to the large quantities of sand that do not effectively retain trace amounts of mercury (Figure 6). However, a definite northwest trend emerged from the data, as well as an anomalous high that was located north of the northwest corner of Bravo 19 near Lee Hot Springs (200 to 212°F surface waters). Bruce (1980) also reported on three thermal gradient holes in the Bravo 19 range (Figure 7, Holes TG 20, 21, and 22). The holes were not located using mercury anomalies but were drilled to test the subsurface temperatures. All three holes had gradients less than 5.2°F/100 feet (9.5°C/100 meters). From this and lineament interpretation, Bruce thought that the best geothermal potential of Bravo 19 existed along the northwest boundary near Lee Hot Springs.

The mercury survey from Bravo 16–the only physical evidence for geothermal fluids that Bruce could report on–provided ambiguous results (Figure 8).

THE KATZENSTEIN AND DANTI REPORT–1982

After Bruce (1980) published his report on the Fallon area, the Navy continued its exploration effort early in the 1980s with additional thermal gradient drilling and with attempts to define structural trends cutting through the NAS Fallon area. This effort was reported by Katzenstein and Danti (1982).

On Mainside, five additional thermal gradient holes were located using the results of the mercury study (Figure 4, Holes TG 27 through TG 31). The four holes drilled on the northwest trending mercury anomaly in the northeast quarter of Mainside exhibited gradients ranging from 5.4 to 5.7°F/100 feet (9.8 to 10.3°C/100 meters). The fifth hole was drilled on the west central boundary of Mainside and had a recorded temperature gradient of 5.2°F/100 feet (9.5°C/100 meters).

The Navy also drilled a 2025-foot observation hole (Fallon Observation Hole (FOH)-1) in the southeast corner of Mainside to test deeper subsurface temperatures. From the surface to total depth, the rock type was unconsolidated sediments, although the bottom 200 feet or so was mixed with a large amount of volcanic detritus. (The rock type described here varies somewhat from the statement made by Katzenstein and Danti (1982) that a rhyolitic layer was present from 1800 feet to total depth.) After the hole had reached thermal equilibrum, a bottom hole temperature of 206°F was recorded, giving a total-hole thermal gradient of 7.6°F/100 feet (13.8°C/100 meters). This observation hole will be discussed more fully in a later section.

In addition to the thermal gradient holes drilled on Mainside, seven more thermal gradient holes were drilled on Bravo 16 (Figure 9, Holes TG 32 through TG 38), and two more were drilled on Bravo 19 (Figure 7, Holes TG 39 and TG 40). The resultant gradient's on Bravo 16 ranged from 4.2 to 5.4°F/100 feet (7.6 to 9.8°C/100 meters); the additional gradients found on Bravo 19 did not exceed 3.8°F/100 feet (6.9°C/100 meters).

The subsurface structural definition effort, which used gravity and magnetic techniques, did not significantly change the interpretations presented by Bruce (1980). These geophysical techniques delineated a large fault along the southeastern boundary of Mainside that directly underlies the high mercury anomaly found by the mercury study of the area (Bruce, 1980). This fault is probably acting as a conduit for geothermal fluids rising from greater depths (Figure 10). The geophysics also delineated a potentially interesting structural feature near the center of Mainside. Because this feature is shown more readily by magnetic methods, it could be explained as an upwarping of the underlying basaltic flows, a western extension of the Lahontan Mountains, or possibly a cooled intrusion (sill) emplaced during the same volcanic episode that created Rattlesnake Hill or the Soda Lake Craters (Figure 11). The structural feature is reflected in the mercury survey of Mainside as an anomalous mercury low, indicating little, if any, geothermal fluid leakage upward through it (Figure 5).

On Bravo 16, the geophysical techniques delineated a doming or upwarping of the basement in the southern half of the range paralleling the Dead Camel Mountains. This was interpreted as a buried eastward extension of the range. North of this feature, the geophysics inferred a very complex basement structure interpreted to be the result of the intersection of two fault zones, the Walker Lane Trend and the Wildcat Fault Zone.

On Bravo 19, the high concentration of sand hampering the interpretation of the mercury survey also hampered the geophysical data gathering by causing lack of mobility. The magnetic survey in the area proved to be too ambigious to use because of wild swings in the data over small distances. However, the gravity data indicated a large northwest-trending fault zone apparently contributing to the uplift of the Blow Sand Mountains.

Of the three sites studied, Katzenstein and Danti (1982) concluded that Mainside has the best geothermal potential because of the high thermal gradients, the high mercury concentrations suggesting substantial subsurface geothermal fluids, and the good subsurface fracture pattern implied by the geophysics and mercury study. Results of the drilling of FOH-1 in the southeast corner of Mainside suggested that temperatures as great as 300°F might exist at a 3500-foot depth (about 1000 feet deeper than Bruce's estimate). Bravo 19 was considered to have the next best potential because of the range's proximity to Lee Hot Springs and the increasing thermal gradients toward the northwest corner of the range. Bravo 16 was considered to have marginal geothermal potential but was a good target for further work.

HELIOSCIENCE GENERAL JOINT VENTURE–1983, 1984, AND 1985

On 29 April 1983 a contract was awarded to General Ener-Tech, San Diego, to develop the suspected geothermal resource beneath Mainside for the benefit of the Navy. This effort was awarded as a third-party contract at no cost to the government or the Navy. However, the contractor was unable to generate adequate funding and, by August 1983, all work on the project had stopped. To continue the effort, General Ener-Tech formed a joint venture with Helioscience, Inc., New York, on 28 November 1983. This new venture was known as the Helioscience General Joint Venture.

As part of the development process, Helioscience General Joint Venture had an independent contractor (GeothermEx, Inc., Richmond, Calif.) appraise the geothermal potential at Mainside. This contractor concluded that a significant geothermal resource existed in the southern part of Mainside, with a possible 300°F system as shallow as 3500 to 4000 feet and extending to depths as great as 8000 feet. The contractor also concluded that the Mainside reservoir should support an installed capacity of 47 megawatts electric (MWe) for 30 years.

Helioscience General Joint Venture then began to perform the contractually required work, obtaining all appropriate permits, licenses, approvals, waivers, and insurance to begin exploratory drilling. They installed all required access roads and well-pad sites for the first three exploratory wells (Figure 12).

However, before moving the drilling rig on to the first site to begin exploratory drilling, it became apparent to Helioscience General Joint Venture that the economics of the project had taken a downturn that rendered the project unfeasible. Attempts to negotiate more favorable economic terms with the Navy were unsuccessful, and Helioscience General Joint Venture served

notice of its intent to terminate the project. Before termination, Helioscience General Joint Venture had to provide drill-site restoration, which consisted of filling the three well cellars and erecting a 5-strand barbed-wire fence around the three sumps. The offical termination date was established as 17 October 1985.

When it became apparent to the Navy that Helioscience General Joint Venture would terminate its development efforts at NAS Fallon, the Navy requested funds to drill a slim core hole on one of the existing Helioscience General Joint Venture drill pads in an attempt to provide more information about the reservoir at Mainside. Although funds were available in fiscal year 1985, drilling was postponed until fiscal year 1986 because of contractual procedures. Longear Drilling Co., Minneapolis, Minn., was awarded the final contract; drilling of the second Fallon Observation Hole (FOH-2) began in May 1986 on Helioscience General Joint Venture's pad FASGE No. 1-36 (Figure 12).

FOH-2, NAS FALLON (JUNE 1986)

GEOLOGIC AND DRILLING SUMMARY

FOH-2 was drilled in the southeast corner of Mainside to a depth of 4485 feet. The hole intersected 2223 feet of sediments, followed by 2262 feet of volcanics. This section is a brief overview of rock units intersected by FOH-2. The appendix contains a detailed lithology log.

The sediments are predominately sands, clays, and shales that were deposited in lake, stream channel, and alluvial fan environments. These units were probably all deposited in the Quaternary period and are Lake Lahontan and associated sediments and younger.

The volcanics encountered are primarily olivine basalts with some interlayered basaltic tuffs, volcanic sediments, and very sparse pyroxene andesites. These are probably a northern extension of the Bunejug Formation of Pliocene to early Pleistocene age (Morrison, 1963). These volcanics have been mapped to thicknesses of over 2000 feet in the Bunejug and Cocoon Mountains, 6 miles southeast of the drill site. The unit is also equivalent to the Chloropagus Formation found in the Desert Peak area.

To avoid confusion, these volcanics are not equivalent to other volcanics that outcrop near the base and form the major freshwater aquifer in that area. Rattlesnake Hill and the extrusives associated with it are Quaternary basalts, mostly black to dark gray flows that were extruded by quiet eruptions from the Rattlesnake Hill vent. These rocks are younger than, or contemporaneous with, the Lahontan sediments.

The effect of the movement of warm to hot hydrothermal fluids through the rocks can be seen both macroscopically and in thin section. The most noticeable effect on the sediments is the formation of secondary pyrite and a slight H_2S odor from some of the samples. In the upper section (down to about 1500 feet), pyrite nodules are small, ranging up to 0.01 inch (0.3 millimeter) in diameter; in the lower section their size increases. From a depth of about 1900 feet to the top of the volcanics at 2223 feet, nodules up to 1.5 inches (38 millimeters) in diameter were recovered from the shales and clays interbedded with the major sand units.

In looking at the volcanics, hydrothermal alteration is apparent throughout the entire section. The majority of the basalts in the drill hole are altered to varying degrees. The basaltic matrix is altered to clays, often containing ghost feldspar laths and pyroxene and hornblende crystals. Secondary calcite, opal, quartz, and possibly zeolites can be seen as vug and fracture filling and as pseudomorphic crystal replacements of the pyroxenes and hornblendes. Most of the original opaque minerals (usually titanomagnetite material) are gone, replaced by secondary minerals, such as euhedral to subhedral pyrite.

Some of the rocks are still quite fresh and show the original microscopic texture. These rocks tend to be unfractured and not vesiculated. The olivine basalts show plagioclase (probably labradorite), olivine, and orthopyroxene phenocrysts in a finely crystalline matrix of feldspar laths, opaque minerals, and pyroxene. In other basalts, olivine is absent and hornblende occurs together with the two pyroxene minerals.

According to the driller's log, drilling circulation was lost three times, twice in the sedimentary units and once in the volcanics. In the sediments, circulation was initially lost at 120 feet and again at about 1560 feet. The 120-foot depth marks the top of the first aquifer below the surface sands. No drilling problems were encountered here. At the second lost-circulation zone, the drillers had to pull out of the hole because of a plugged bit; it took 4 hours to wash back in (to remove sand that had fallen in) and recover circulation.

Drilling fluids were lost again in the brecciated basalts at about 2325 feet. It took several hours and 42 bags of drilling material to regain adequate circulation. At about 2400 feet (again in brecciated basalts) the drillers reported intersecting another aquifer and that the aquifer was producing a small amount of water. This net water gain did not last, however, and over the total length of the hole there was a substantial water loss.

There are distinct differences in the properties of porosity and permeability between the two major rock units encountered in the drill hole. In general, the clastics of the upper major unit were all friable, poorly to well sorted, fine sand to medium gravel. Some contained interstitial clay, but most were clean units interbedded with mud and clay stringers and separated by some thick lacustrine clay sections. There is no evidence of any alteration of porosity in this section by the hydrothermal fluids. These units would make good aquifers but their lateral continuity is unknown. Except for the interlayered tuffaceous or sedimentary units, the volcanic sequence (lower major unit) had poor primary porosity. Moderate fracturing and some severe brecciation has taken place over much of the section, creating a secondary porosity and facilitating the rock alteration. It is unknown what level of permeability, and subsequent fluid flow, this secondary porosity would sustain. There was no spontaneous flow from the drill hole after drilling was completed and the drill string removed, and no attempt was made to unload or produce fluids from the hole.

FOH-2 THERMAL GRADIENT AND HEAT FLOW

The thermal gradient in FOH-2 was logged by the U.S. Geological Survey (USGS) on 19 June 1986 (approximately 10 hours after final mud circulation), and again on 13 August 1986, 55 days after the completion of drilling. Profiles of both are shown in Figure 13.

We expected the bottom-hole temperature to rise between the 19 June and 13 August 1986 gradient measurements, but comparison of the two gradients reveals that the temperature at the bottom of the hole had equilibrated at approximately 311°F within 10 hours after completion of mud circulation. However, the rest of the hole cooled slightly in that time interval. A small perturbation in the gradient measured on 13 August near 2400 feet indicates the top of the volcanic layer. A small inflection at 1500 feet and 158°F probably indicates a hot-water aquifer. Assuming a mean ambient temperature of 53°F, the overall measured gradient of the 13 August profile (which is assumed to be very near equilibrum) is 5.7°F/100 feet (10.4°C/100 meters). This is well above the average thermal gradients of the Basin and Range province, which range from 1.7 to 2.8°F/100 feet (3.0 to 5.0°C/100 meters).

Also during the drilling of FOH-2, core samples were taken approximately every 100 feet within the volcanic sequence for thermal conductivity determinations. Thermal conductivity is the amount of heat that a given material (in this case, volcanic rock) will conduct in a given amount of time. Thermal conductivity multiplied by the thermal gradient gives the uncorrected heat flow. As defined by Sass and others (1981), the term "heat flow" usually means the vertical component of heat being conducted through the outer kilometer or so of the earth's crust. Corrected heat flow generally takes into account the effects of topography and other variables, but because FOH-2 is located on a very flat plain, the uncorrected value is as accurate as needed. The calculated heat flow of FOH-2 was 3.01 heat flow units (HFU) (1 HFU - 1 μcal/cm^2-sec). This value agrees with other heat-flow values determined in the portion of Nevada known as the Battle Mountain High Heat Flow Province.*

DISCUSSION AND A POSSIBLE RESOURCE MODEL

THE HOT AQUIFER

On 18 June 1986, while waiting for FOH-2 to be lined, the USGS measured the thermal gradient of FOH-1 on a two-foot interval. This was the first time FOH-1 had been measured at this interval and the first time since 1981 that the gradient was observed. The gradient, shown in Figure 14, reveals what we feel is a warm-water aquifer between 1040 and 1320 feet. The temperature of the aquifer is about 158°F. The temperature at the bottom of the hole (2000 feet, or 609.6 meters) was recorded at 216.9°F. Assuming a surface mean temperature of 53°F, the thermal gradient over FOH-1 is 8.2°F/100 feet (14.9°C/100 meters). However, the thermal gradient above the aquifer is 9.6°F/100 feet (17.4°C/100 meters), while the gradient below is 7.0° F/100 feet (12.7°C/100 meters).

The thermal gradient of FOH-2 was measured on 19 June and 13 August 1986 (Figure 13). Inspection of the thermal gradient taken in August indicates that FOH-2 did not intersect the main reservoir because the gradient remained conductive and did not become isothermal. There is a slight inflection point at 1500 feet and 158°F, which we think corresponds to the shallow aquifer seen in FOH-1. The inflection point is not as pronounced in FOH-2, probably indicating that the aquifer is pinching out near FOH-2. Assuming an ambient temperature of 53°F (which allows consistency with the rest of the exploration effort at NAS Fallon), the thermal gradient

*Personal communication between A. M. Katzenstein and J. H. Sass, 1986.

of FOH-2 is 5.7°F/100 feet (10.4°C/100 meters). However, the gradient above the inflection point is 6.6°F/100 feet (12.0°C/100 meters); the gradient below is 5.1°F/100 feet (9.3°C/100 meters).

The 158°F aquifer found in both FOH-1 and FOH-2 probably explains the high thermal gradients seen in holes TG 24 and TG 26 (see Figure 4). Because these holes were not drilled deeply enough to penetrate the aquifer, their thermal gradients would be anomalously high because of the heat content of the aquifer. We have already shown how the presence of the aquifer affects the thermal gradients of FOH-1 and FOH-2. However, with the exception of these four holes (FOH-1, FOH-2, TG 24, and TG 26), we do not feel that the aquifer affects the gradient values of any other thermal gradient holes drilled at Mainside.

Figure 15 is a contour map of thermal gradients of all exploration holes at Mainside using total hole temperatures and assuming a mean ambient surface temperature of 53°F. The effect of the warm-water aquifer can be seen in the southeast corner of Mainside as a pronounced, unclosed, high anomaly. However, in order to present what we feel is a more accurate picture of the thermal gradients below Mainside, we subtracted the thermal contribution of the suspected warm-water aquifer. Thermal gradient values from holes TG 24 and TG 26 were therefore excluded, as were the thermal gradient values above the aquifer in FOH-1 and FOH-2. We also excluded Well 0 since we do not know how it was completed. In addition, to remove any near-surface disturbances, we considered only the thermal gradients from a depth of 100 feet to total depth in the remaining holes. The resultant contour may, Figure 16, indicates that although the southeast corner of the base is still a good exploration target, it does not have as pronounced a thermal high as depicted in Figure 15.

After dwelling in the past few paragraphs on the negative aspects of what the hot aquifer did to thermal gradients at Mainside, we want to mention that warm or hot shallow aquifers have been associated with many, if not all, discovered geothermal systems in the northern Basin and Range province. The most notable system discovered because of shallow aquifers was Desert Peak. The extent of the aquifers did not necessarily align with the delineated limits of the reservoir at Desert Peak, but the presence of the aquifers supplied the "bait" for continued drilling by Phillips Petroleum Co. until they drilled exploration Well B21-1 and discovered the resource.

Hot aquifers tend to indicate leakage of geothermal fluids along nearby faults. As suggested by Figure 16, the fault providing the aquifer fluids that we infer at Mainside is located to the east of FOH-1. This observation is further supported by mercury, gravity, and magnetic data gathered in earlier stages of exploration (as described in an earlier section of this report).

RESERVOIR ROCK

Along with testing for subsurface temperatues, another important reason for drilling FOH-2 was to provide new insights into the local geology of and around Mainside. We had expected to intercept what Hastings (1979) called the "capping basalt" unit within the Fallon Basin, at roughly the depth the basalts were reached (2250 feet). We also expected to drill through this unit into the "middle sedimentary unit" (Hastings, 1979), which we felt held the resource fluids. Instead, the drill hole bottomed in Tertiary volcanics (possibly capping basalts) at nearly 4500 feet. The thermal gradient remained conductive to that depth, indicating that the hole had not intercepted the main geothermal resource. As a result, we obtained no information on the possible reservoir rock type.

TEMPERATURE OF THE RESOURCE

There are numerous ways to infer the temperature of the resource at Mainside. The minimum estimated temperature of the resource is 310.5°F, the maximum and bottom-hole temperature of FOH-2. It is also the highest temperature recorded in a drill hole at Mainside. The maximum temperature estimated for the resource is 399°F, calculated by the Na-K-Ca geothermometer on a chemical analysis from Well 6 (Bruce, 1980). However, the maximum temperature estimate may be misleading. Edmiston and Benoit (1984) have observed that in the northern Basin and Range, the Na-K-Ca geothermometer gives results averaging 52°F too high for fluid samples taken from deep wells. The method also overestimates by 30°F the actual reservoir temperatures when sampled from a shallow well. Since Well 6 is a shallow hole (165 feet), the actual resource temperature may be closer to 369°F.

With the above paragraph in mind, it seems constructive to indicate how the temperature profiles of FOH-1 and FOH-2 compare with profiles from other Basin and Range geothermal systems. Edmiston and Benoit (1984) plotted temperature profiles from four moderate-temperature (302 to 392°F) systems (Figure 17) and also from the Roosevelt high-temperature (>392°F) system (Figure 18). Superimposed on these figures are the temperature profiles of FOH-1 and FOH-2. Figure 17 suggests that FOH-2 may have a hotter temperature profile than seen from wells of other moderate-temperature systems and seems to be approaching temperature profiles seen in high-temperature systems (Figure 18). However, the temperature profile of FOH-2 may overturn at some depth and converge, like the other four moderate-temperature profiles, to a temperature of 374°F near 9000 feet (Edmiston and Benoit, 1984).

DEPTH OF THE RESOURCE

Depth to the resource and producing zones can be somewhat implied by the thermal gradients at Mainside and by drawing parallels from the work accomplished by Benoit and others (1982) at the Desert Peak geothermal system. As mentioned before, the Desert Peak reservoir is contained beneath Tertiary volcanic rocks in fractured pre-Tertiary basement rocks whose stratigraphy and structure are not well known. The thick sequence of volcanic rock is an effective caprock to the reservoir. Results from drilling at Desert Peak indicate that the depth to the 400°F isotherm can arbitrarily signify the top of the reservoir. The configuration to the top of the producing zone cannot be contoured because of lack of data. Benoit and others (1982) reported that only two wells (B21-1 and B21-2) provided any reliable information concerning the top of the producing zone. The top of the producing zone in Well B21-1 is at 3638 feet, which is 1908 feet lower than the top of the reservoir (400°F isotherm) and 500 feet below the top of the pre-Tertiary rocks. The top of the producing zone in Well B21-2 is at 2871 feet, 331 feet lower than the top of the reservoir and a mere 63 feet below the top of the pre-Tertiary rocks. The depth of the producing zone in a third well (B21-3) was not known in 1982, but the top of the reservoir was 975 feet below the top of the pre-Tertiary rocks.

The maximum estimated resource temperature at Mainside (369 to 399°F) is near the resource temperature found at Desert Peak (399°F). At both sites the Tertiary volcanic rock is presumed to act as the caprock. The reservoir rock type at Desert Peak is pre-Tertiary basement rock; the reservoir rock type at Mainside is not known. However, by using the bottom-hole temperatures from all wells (excluding TG 24 and TG 26) and the thermal gradients as defined by Figure 16, the depth to the 400°F isotherm is calculated to be 4630 feet below the collar

of FOH-1 and 6240 feet below the collar of FOH-2 (Figure 19). The isotherm then flattens out to the north and west as shown in Figure 20. These results assume that the gradient remains constant to those depths. The depth to any producing zones is probably deeper and may exceed 8000 feet.

Superimposed on Figure 20 is a cross section of the residual gravity discussed in an earlier section. Comparing this cross section with the estimated depth to the 400°F isotherm also strongly suggests that a fault or structural conduit of some sort is responsible for elevated temperatures found in the southeast corner of Mainside.

A MODEL

Although the source of heat is unknown, one model for the hydrothermal system presented for Desert Peak appears to fit what is known to date at Mainside. Yeamans (1983, and the references therein) calculated a depth of circulation as 8200 feet for the hydrothermal system at Desert Peak; this assumed a 399°F reservoir temperature (from geothermometery), a 50°F recharge temperature, and a 4.2°F/100 feet (76.4°C/kilometer) constant conductive temperature gradient. The parameters used to calculate this circulation depth are not much different from what is seen at Mainside. The geometry of the Carson Lake area as determined by gravity (Trexler and others, 1981) strongly suggests that Mainside is on the rising thermal plume of a large convection cell, possibly centered beneath Carson Lake (Figure 21). By using the depth to the top of the Tertiary volcanics as determined by drilling in FOH-2, and the Bouguer gravity values as shown in Figure 21, the depth to the top of the volcanics is calculated to be 5000 feet beneath Carson Lake. The volcanic section has an undetermined thickness but probably exceeds the 2200 feet shown in FOH-2. This puts the entire Tertiary sedimentary/volcanic thickness at more than 7200 feet beneath Carson Lake. A small amount of the fluids, which is warmed by circulating within fractured rocks beneath the volcanics (or caprock), is then thought to rise along a permeable zone within the caprock. This permeable zone is caused by the intersection of three different trending faults located in the southeast quarter of Mainside. The escaping fluid is detectable by the trace mercury study and is seen as the shallow hot aquifer in FOH-1 and FOH-2.

NAS FALLON CONCLUSIONS

1. A moderate- to high-temperature geothermal resource at an exploitable depth underlies the southeastern corner of Mainside. This conclusion is based on interpretations of temperatures and hydrothermal alteration patterns in thermal gradient holes, geophysics, subsurface structural patterns, and the distribution of trace mercury in surface soils.

2. Based on Na-K-Ca geothermometry, the maximum estimated temperature of the resource at Mainside is 369 to 399°F. This temperature was calculated using results of a chemical analysis on fluids from Well 6, a hot artesian well located a few miles south of the base. To date, the maximum recorded temperature measured at Mainside is 310°F at 4485 feet (total depth (T.D.)) in FOH-2. The thermal gradient of this portion of the hole, located in a thick sequence of Tertiary volcanics, was conductive at 5.1°F/100 feet (9.3°C/100 meters). Therefore, from the above evidence, we believe the actual resource temperature is probably greater than 350°F.

3. Expected depth to the resource is approximately 4500 feet in the extreme southeastern corner of the base and near 7000 feet beneath the rest of Mainside. These depths were calculated using bottom-hole temperatures and thermal gradients from numerous shallow to moderately deep drill holes. The abrupt deepening of the resource is due to a north-trending fault that is upthrown on the eastern side and is located near the eastern boundary in the southern half of the base.

4. The existence of the fault discussed above is also inferred by the results from the trace mercury study, gravity, land magnetics, and the presence of a relatively shallow, warm (158°F) aquifer. The aquifer is thought to contain the small amount of hydrothermal fluid that escapes from the geothermal reservoir by convective upwelling along the fault plane. The fluid migrates up through a thick sequence of Tertiary volcanics that act as the caprock to the geothermal system (see paragraph 2 above). These fluids then spread laterally in the sediments that overlie the volcanic rock.

5. Reservoir rock type is not known at this time but is probably a pre-Tertiary basement complex, much like the reservoir rock at Desert Peak. The basement complex beneath the southeast corner of Mainside is probably extensively fractured, as witnessed by surface fault patterns and the results of the trace mercury study. These studies infer an intersection of three faults, all with different trends, just south of the airfield.

6. The amount of geothermal fluid beneath Mainside is not known. However, from the results of drilling at Salt Wells and Stillwater, abundant flow of geothermal fluid is probable at some depth. The presence of the intersection of the three fault planes just discussed is an important point in guessing the fluid content of the reservoir. A highly fractured reservoir rock will contain more fluid than a moderately fractured one and will allow greater transmissivity of the fluids.

7. The source of heat for the system is not known. However, one model that fits the data for the system to date is the existence of a large convection cell centered beneath Carson Lake. This cell is created by the higher than normal thermal gradients in this area (from whatever source), derives its fluids from sources to the west, and loses some of its fluids along its eastern margin where faults cut the caprock (Tertiary volcanics). Such a cell assumes circulation of fluids to a depth of at least 8200 feet and also assumes that a rock type exists that allows such transmissivity. Gravity data taken in the Carson Lake area, coupled with information on the sedimentary thickness inferred from FOH-2, indicate that the bottom of the Tertiary volcanics (caprock) lies deeper than 7200 feet beneath Carson Lake. Although the rock type beneath the caprock is unknown, it could possibly be a fractured pre-Tertiary basement complex. Such a fractured complex would allow for the transmissivity of convecting geothermal fluids.

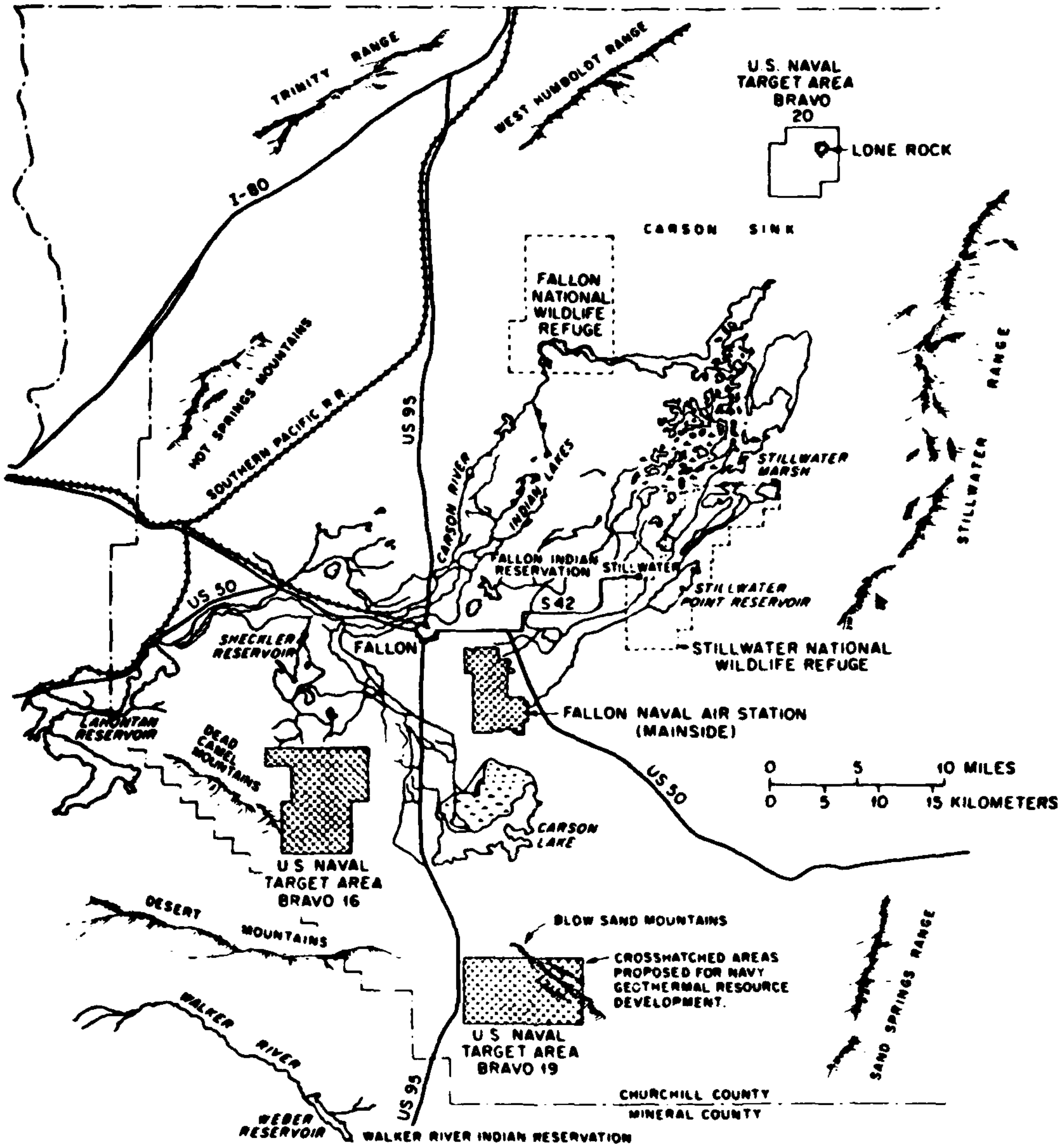


FIGURE 1. Location Map Showing NAS Fallon–Mainside, Bravo 16, and Bravo 19. Modified from Naval Weapons Center (1981).

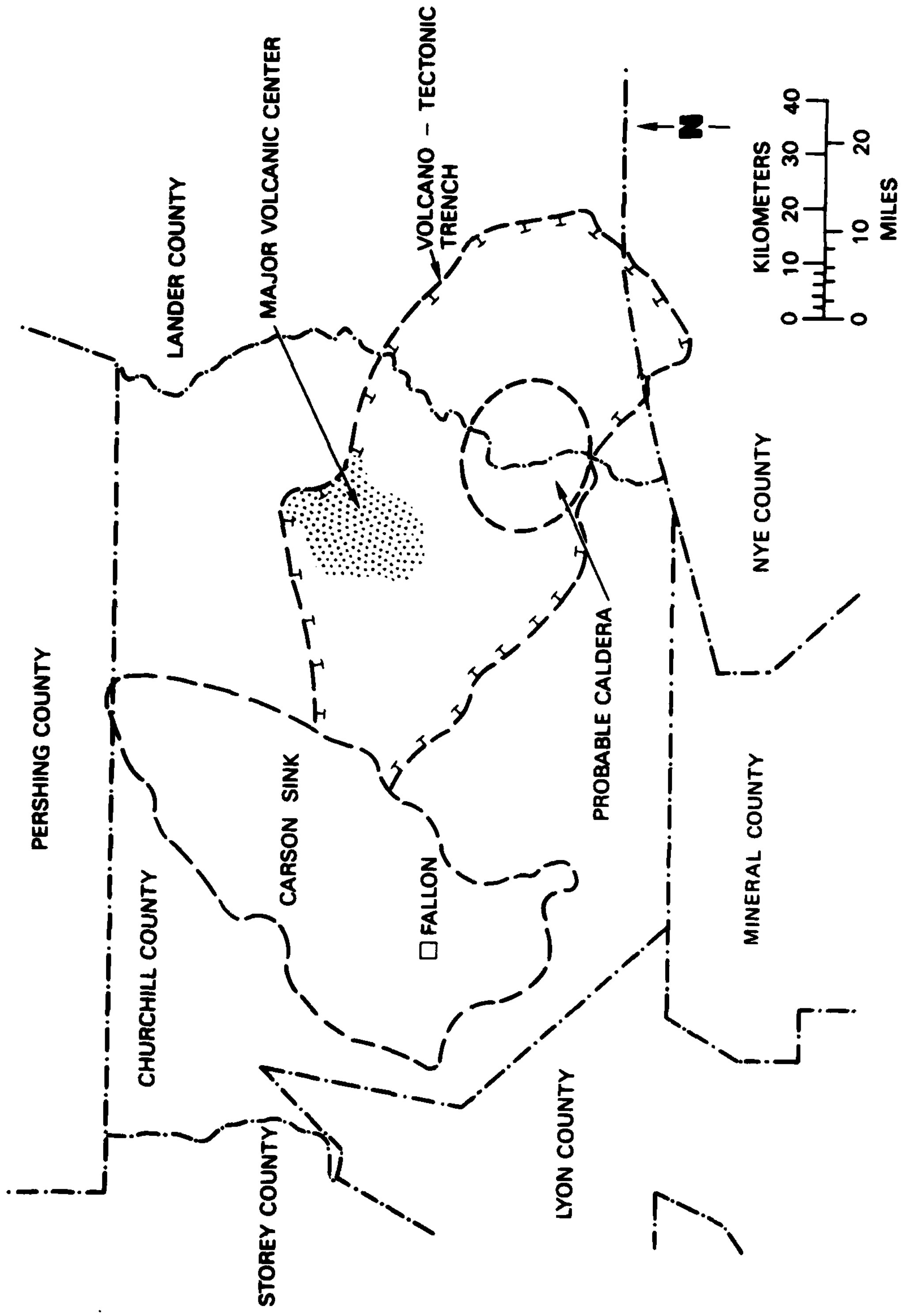
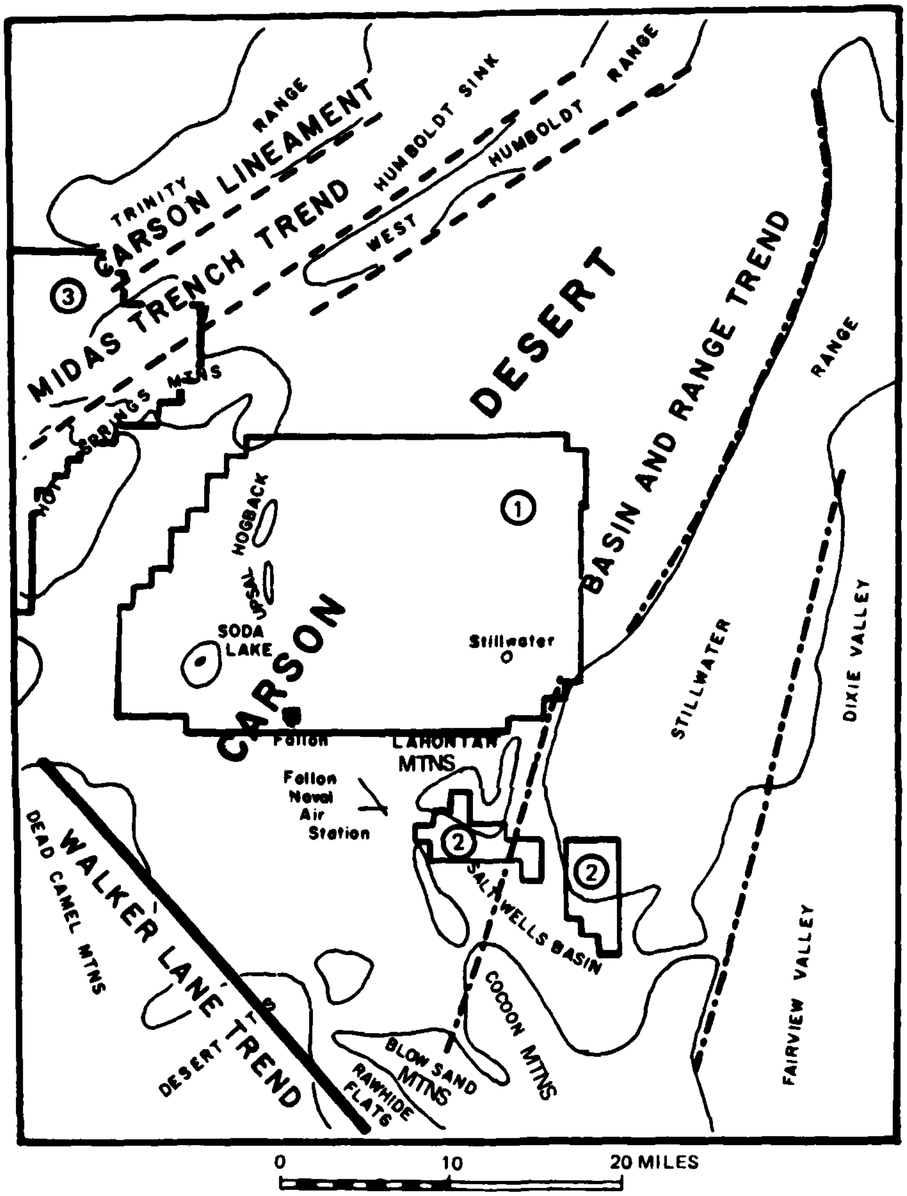


FIGURE 2. Carson Sink. Modified from Stewart (1980).



1. STILLWATER-SODA LAKE KGRA
2. SALT WELLS KGRA
3. DESERT PEAK (BRADY-HAZEN) KGRA

FIGURE 3. Geothermal Areas in and Around Carson Sink. KGRA = Known geothermal resource area. Modified from Katzenstein and Danti (1982).

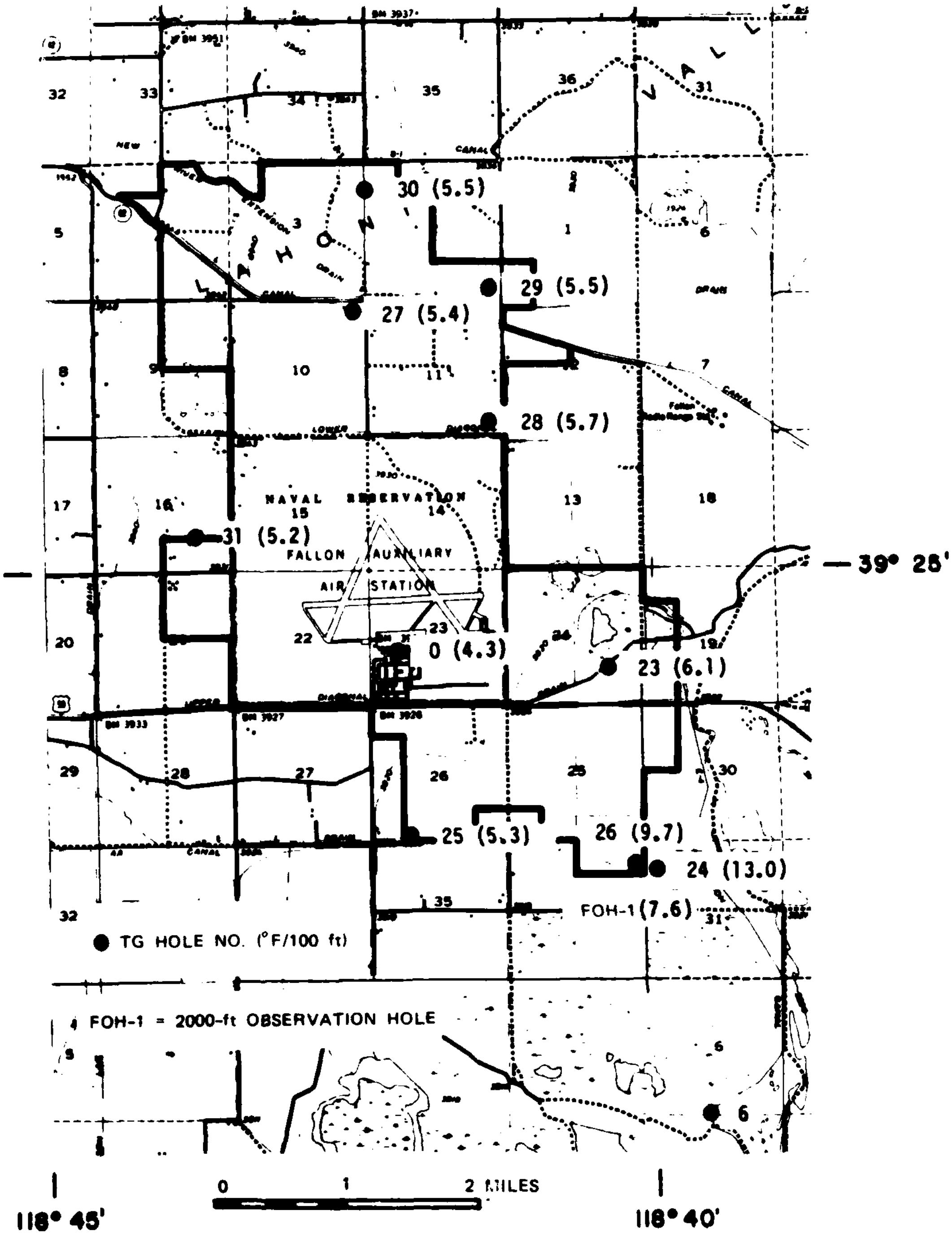
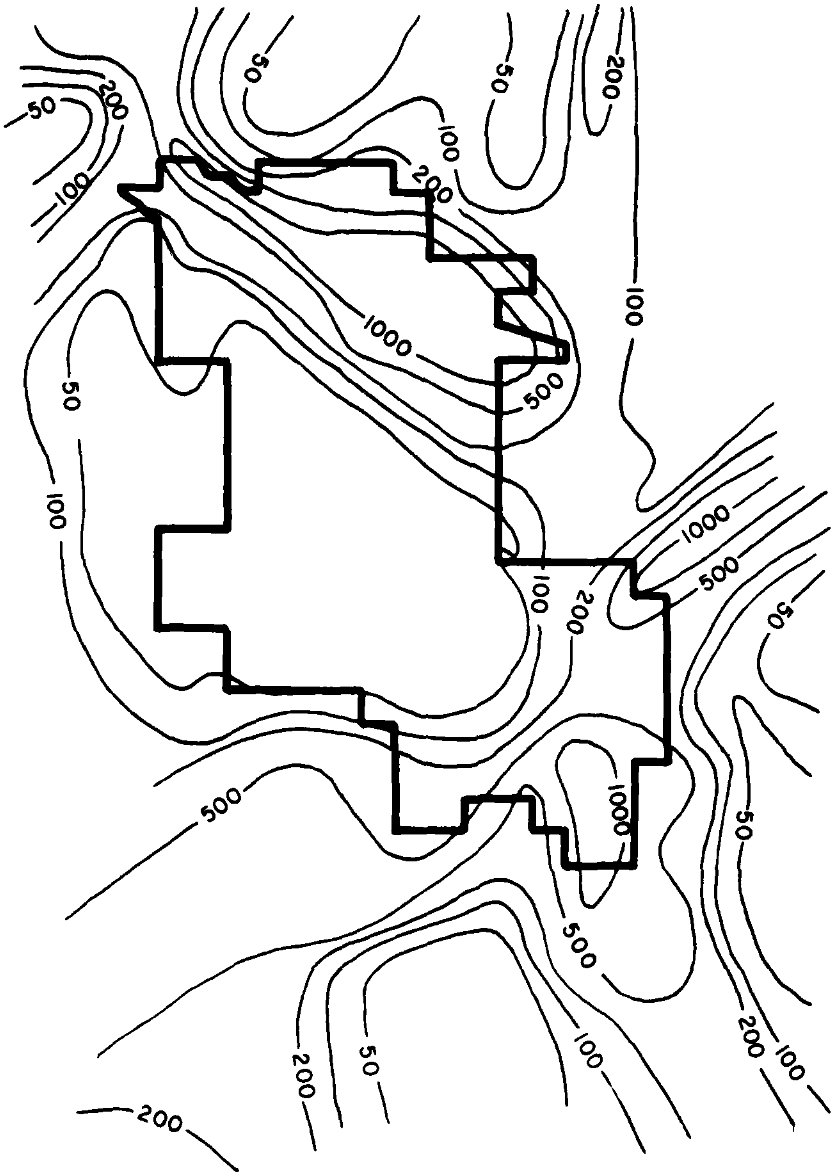
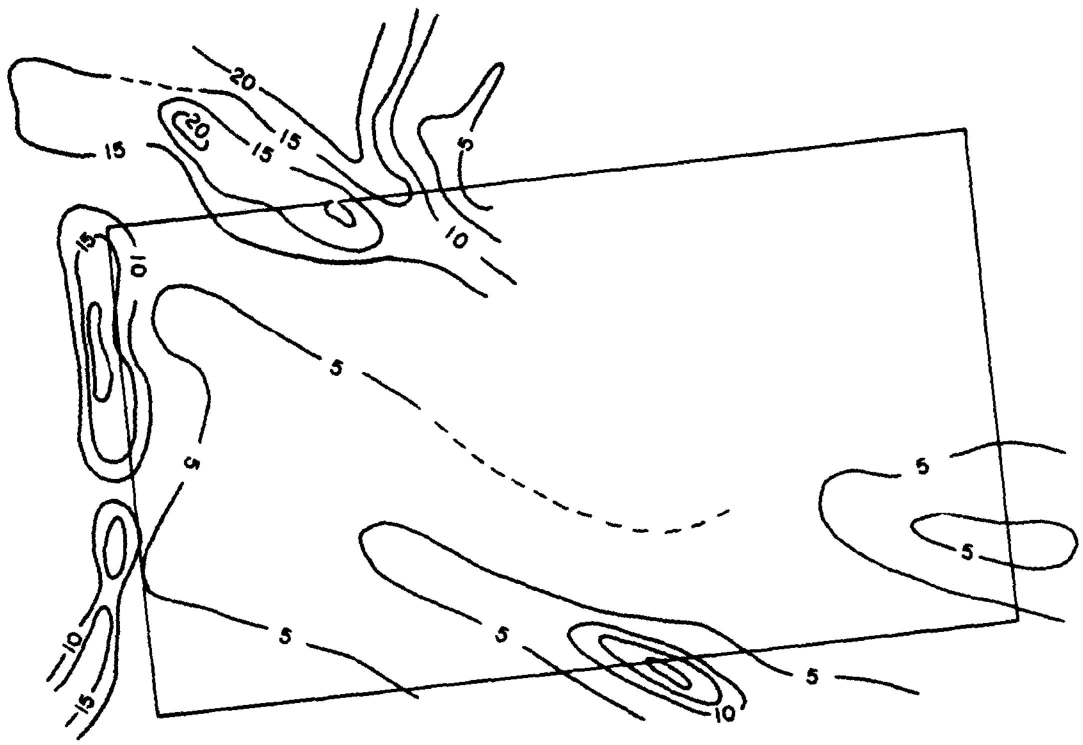


FIGURE 4. Mainside Topographic Map Showing Warm Wells and Thermal Gradient Holes. Modified from Katzenstein and Danti (1982).



CONTOUR INTERVAL = 50, 100, 200, 500, 1000 ppb OF MERCURY

FIGURE 5. Results of the Trace Mercury Study, Mainside. Modified from Bruce (1980). Ppb = parts per billion.



CONTOUR INTERVAL = 5 ppb OF MERCURY

FIGURE 6. Results of the Trace Mercury Study, Bravo 19. Modified from Bruce (1980).

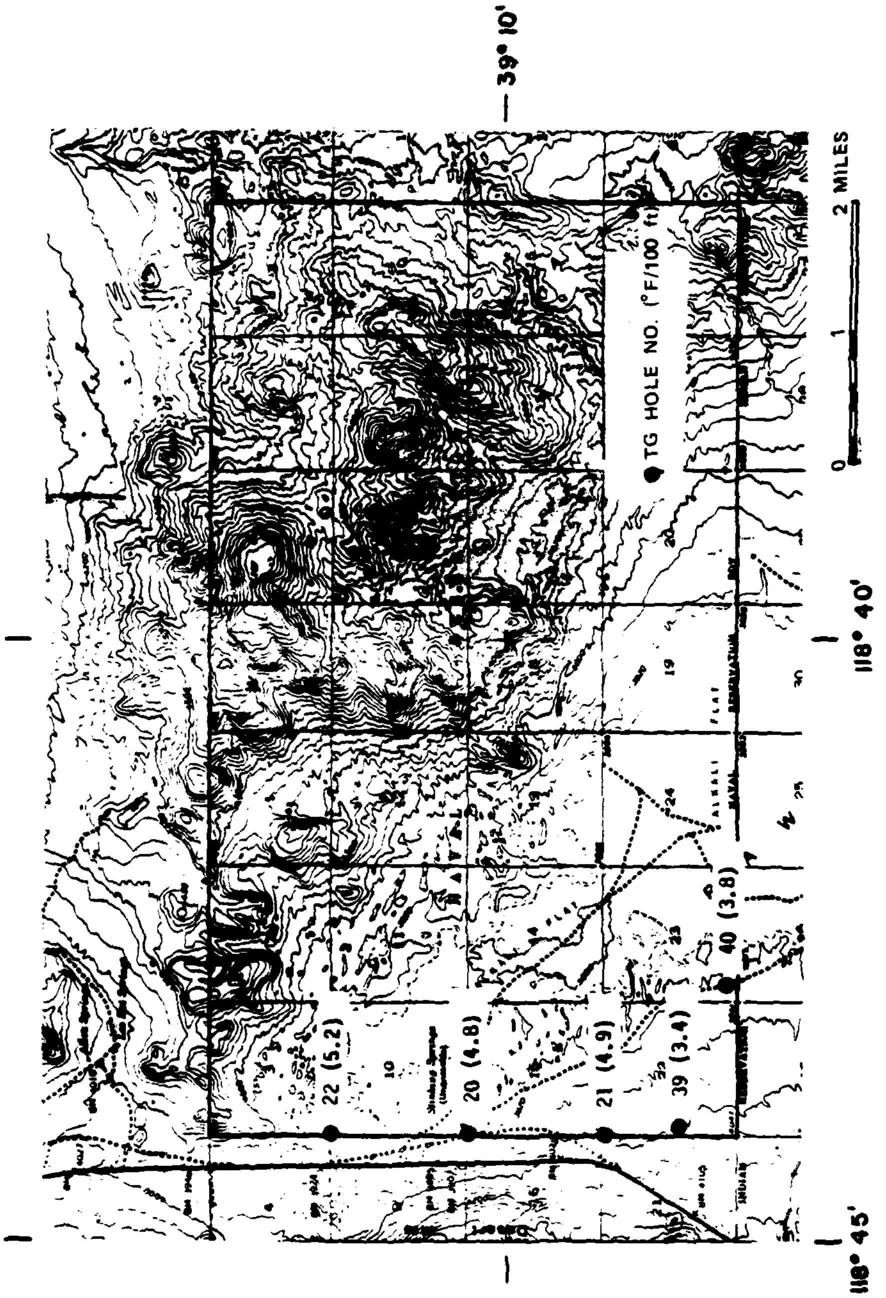
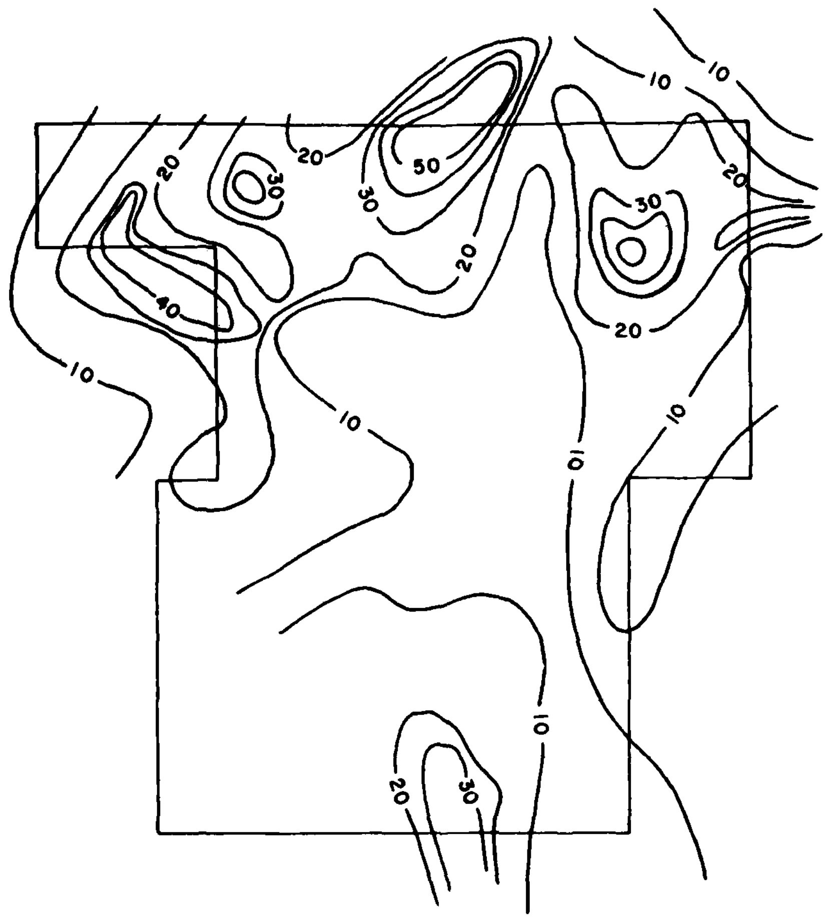


FIGURE 7. Bravo 19 Topographic Map Showing Thermal Gradient Holes. Modified from Katzenstein and Danti (1982).



CONTOUR INTERVAL = 10 ppb OF MERCURY

FIGURE 8. Results of the Trace Mercury Study, Bravo 16. Modified from Bruce (1980).

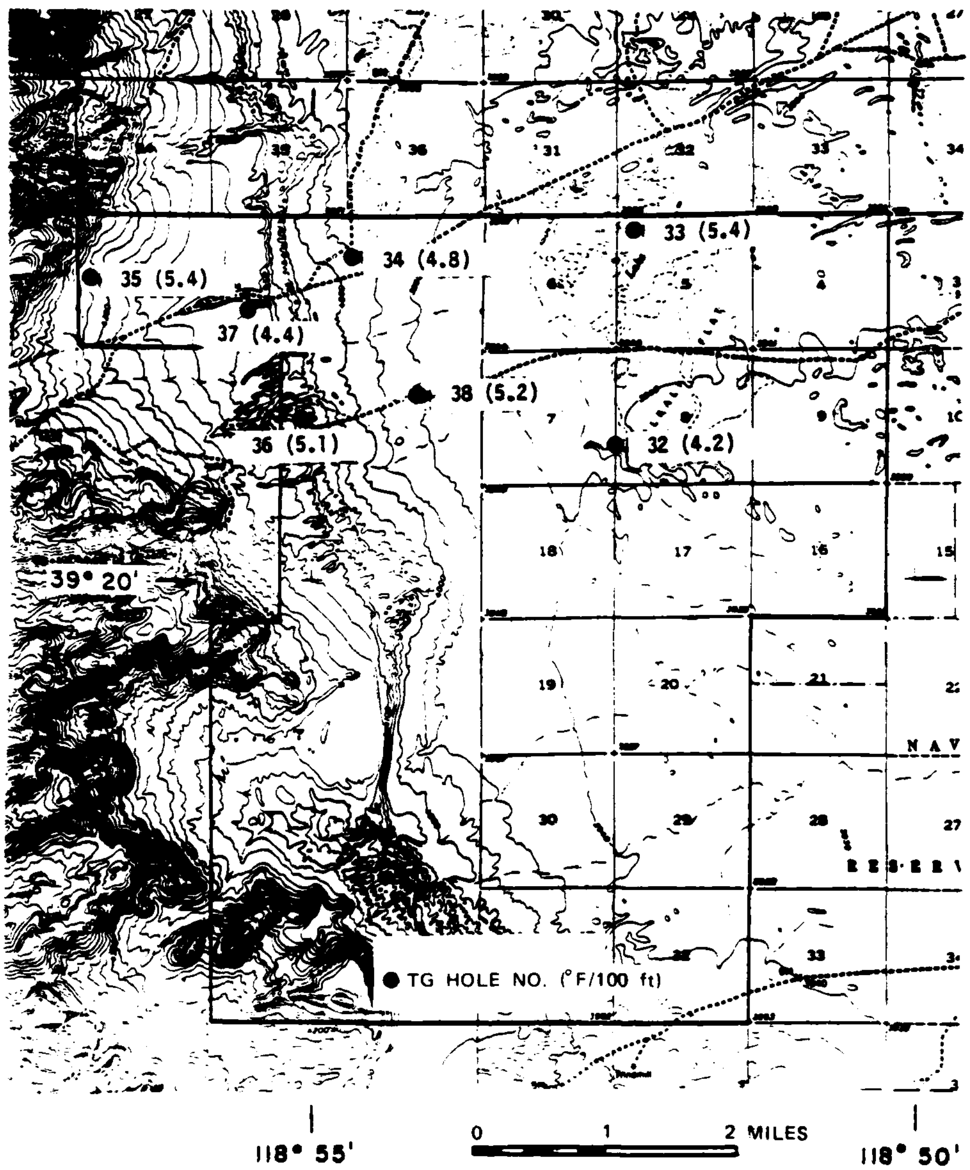


FIGURE 9. Bravo 16 Topographic Map Showing Thermal Gradient Holes. Modified from Katzenstein and Danti (1982).

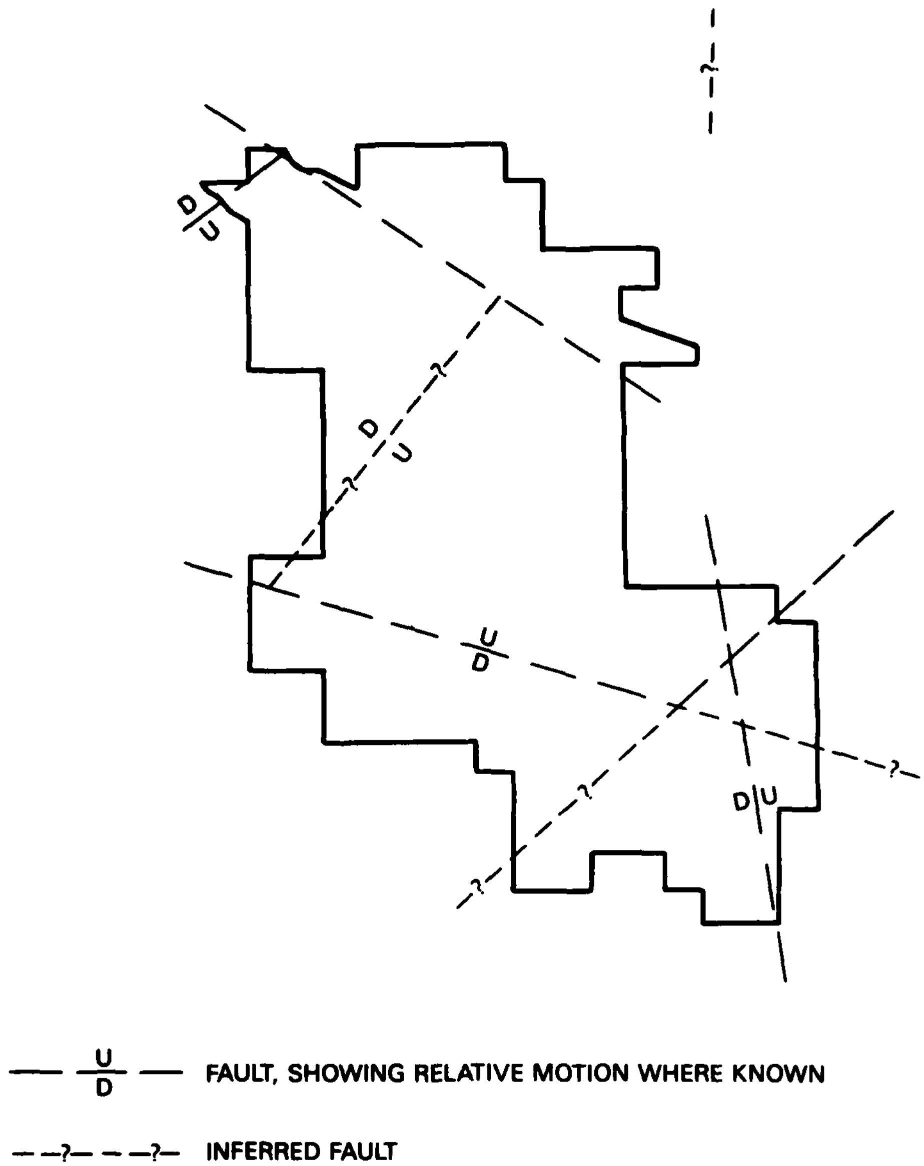
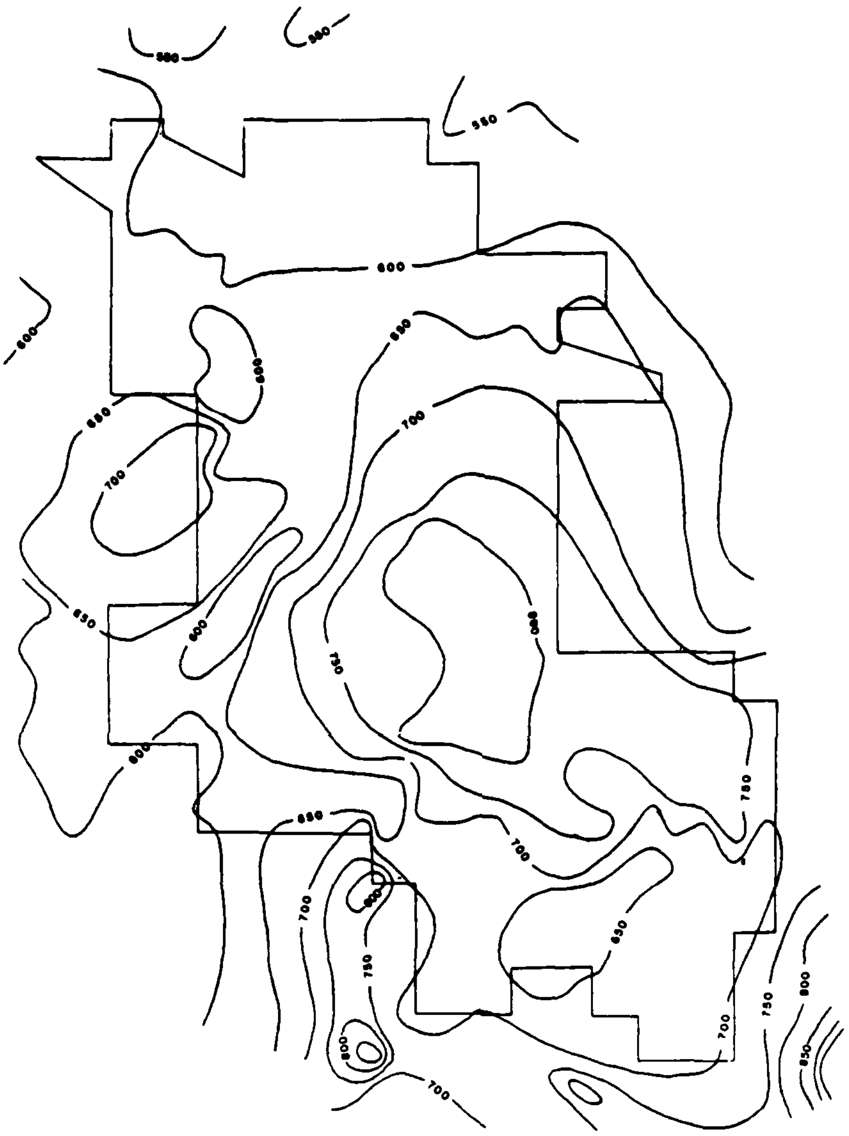


FIGURE 10. Interpretation Map, Possible Fault Locations, Mainside. Data from trace mercury studies, geophysics, and thermal gradient holes. Modified from Katzenstein and Danti (1982).



CONTOUR INTERVAL = 50 GAMMAS
ALL VALUES +52,000 GAMMAS

0 1 2 MILES

FIGURE 11. Total Intensity Land Magnetic Map, Mainside. Modified from Katzenstein and Danti (1982).

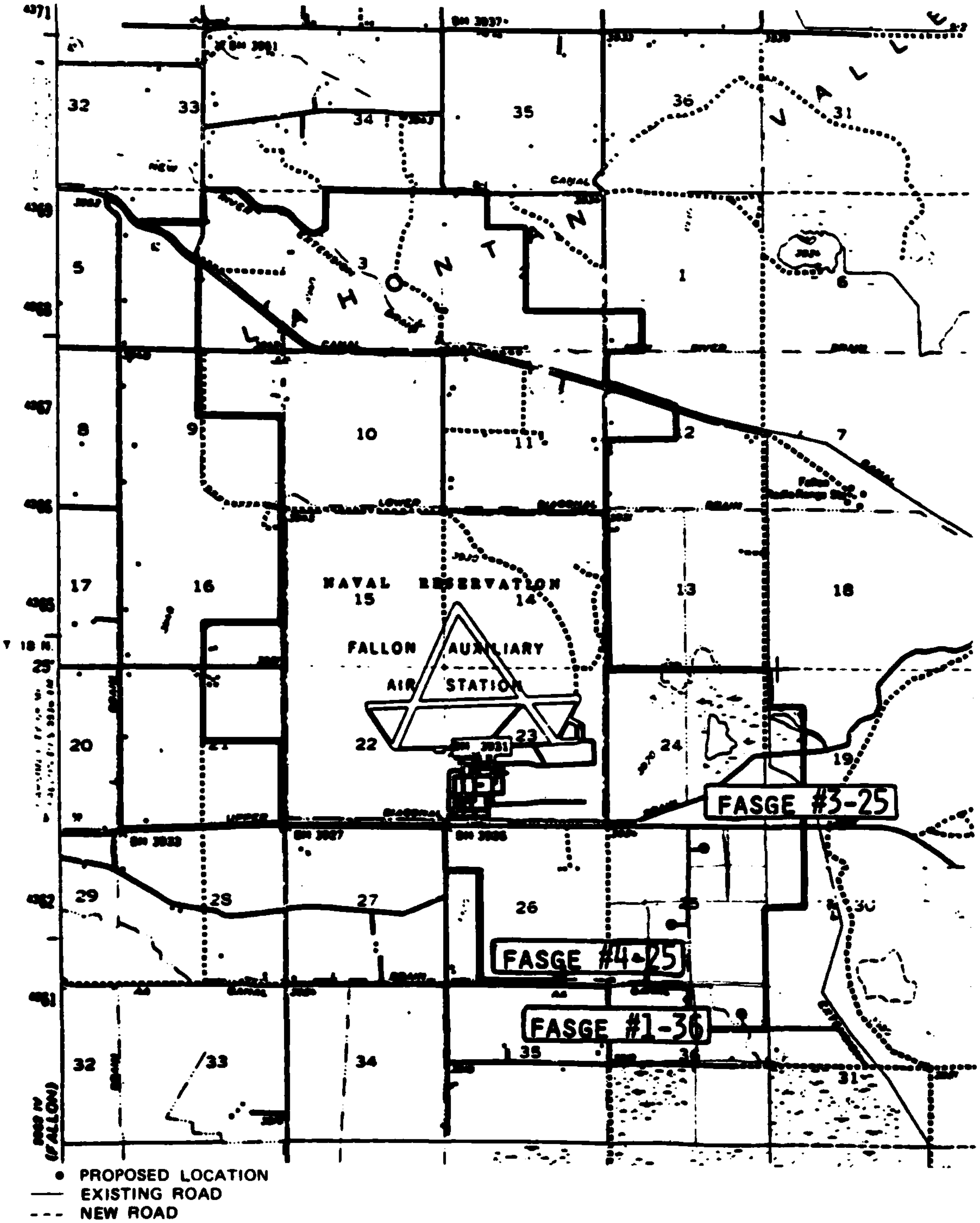


FIGURE 12. Proposed Locations for Mainside Geothermal Exploration Wells. Modified from Helio-science General Joint Venture (1985). FASGE #1-36 is location for FOH-2.

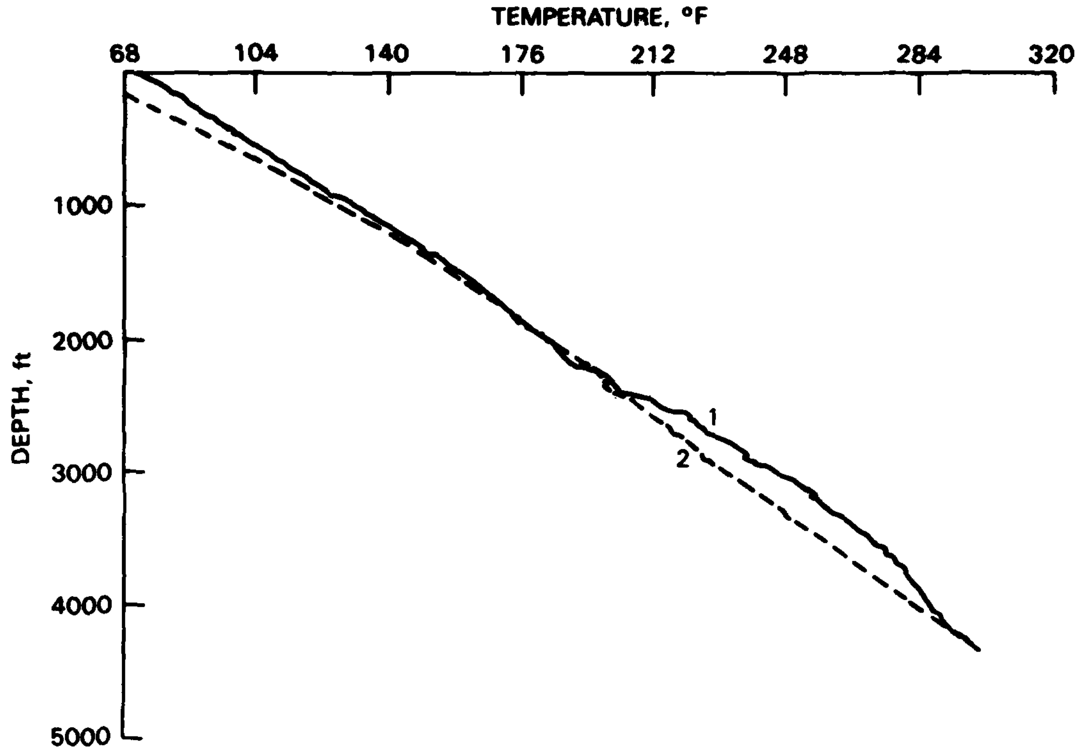


FIGURE 13. FOH-2 Temperature Log. 1 = temperature logged 19 June 1986; 2 = temperature logged 13 August 1986.

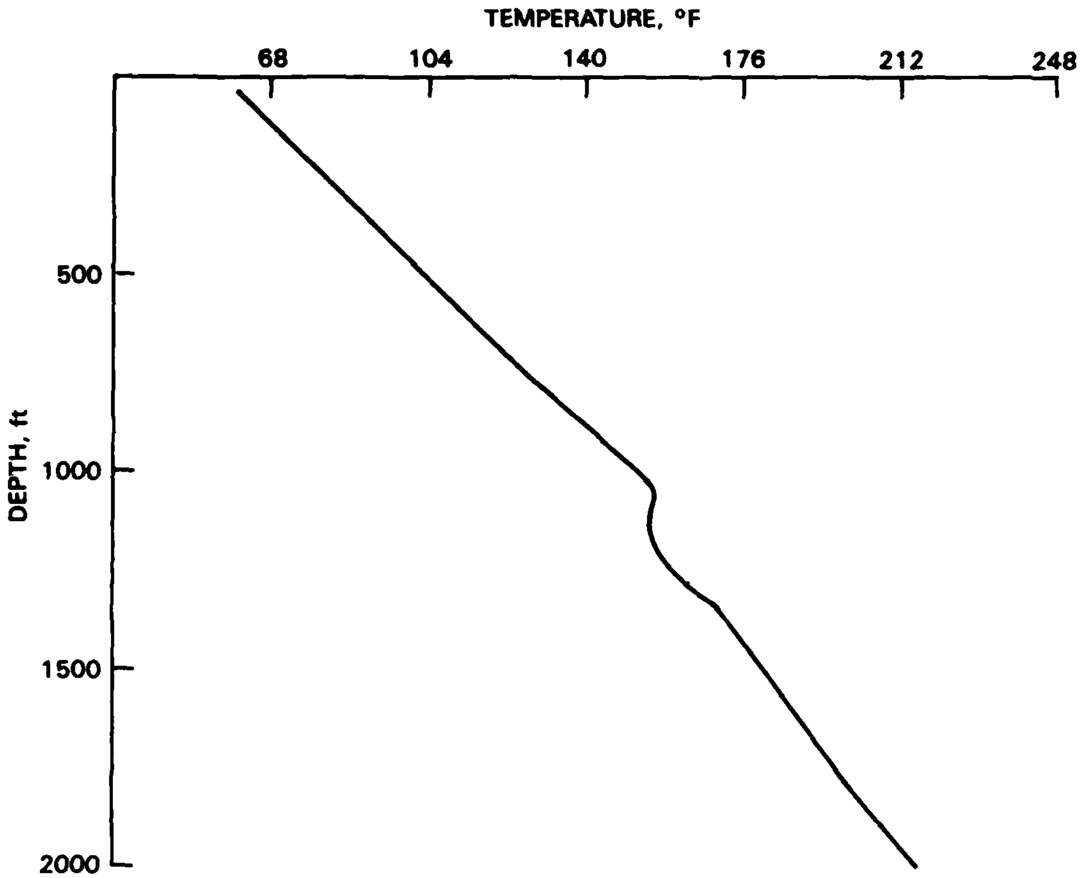


FIGURE 14. FOH-1 Temperature Log for 18 June 1986.

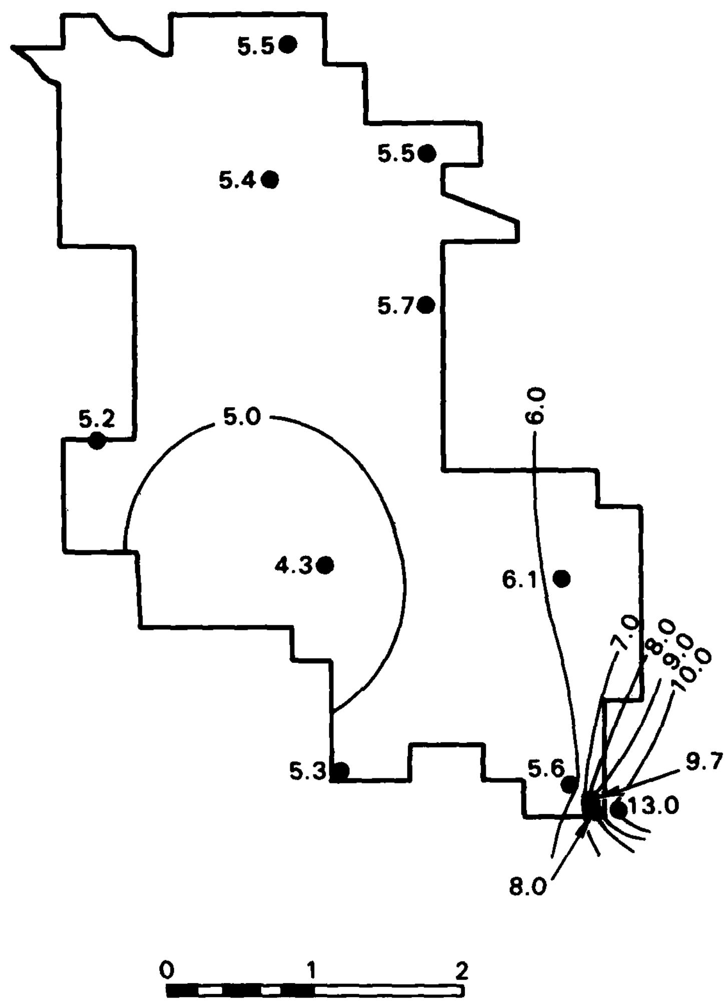


FIGURE 15. Contour Map of Thermal Gradients at Mainside Using Total-Hole Temperatures.

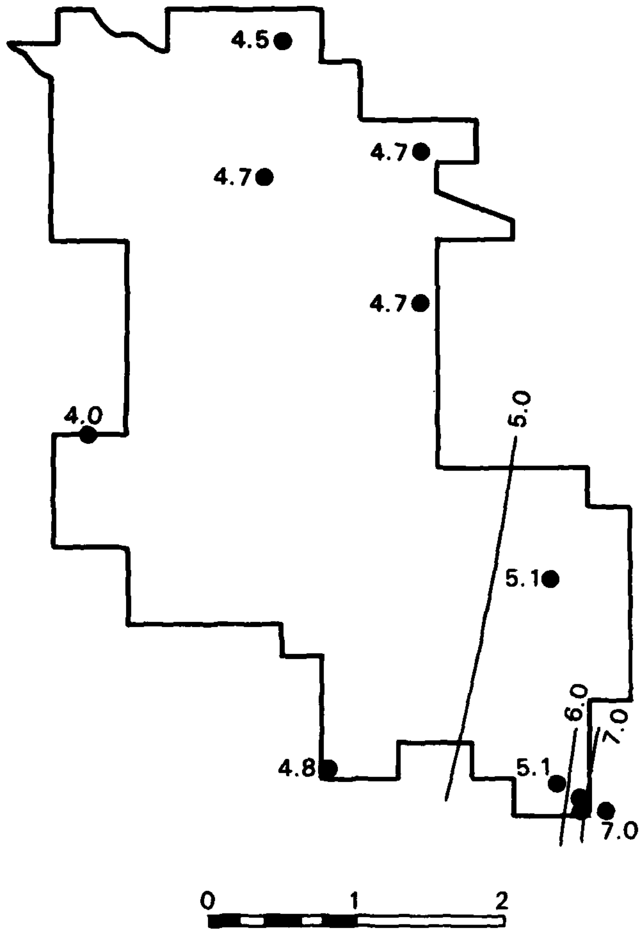


FIGURE 16. Contour Map of Thermal Gradients at Mainside Omitting Values From Holes TG 24 and TG 26 and Using Only TG Values Below the 158°F Inflection Point in FOH-1 and FOH-2.

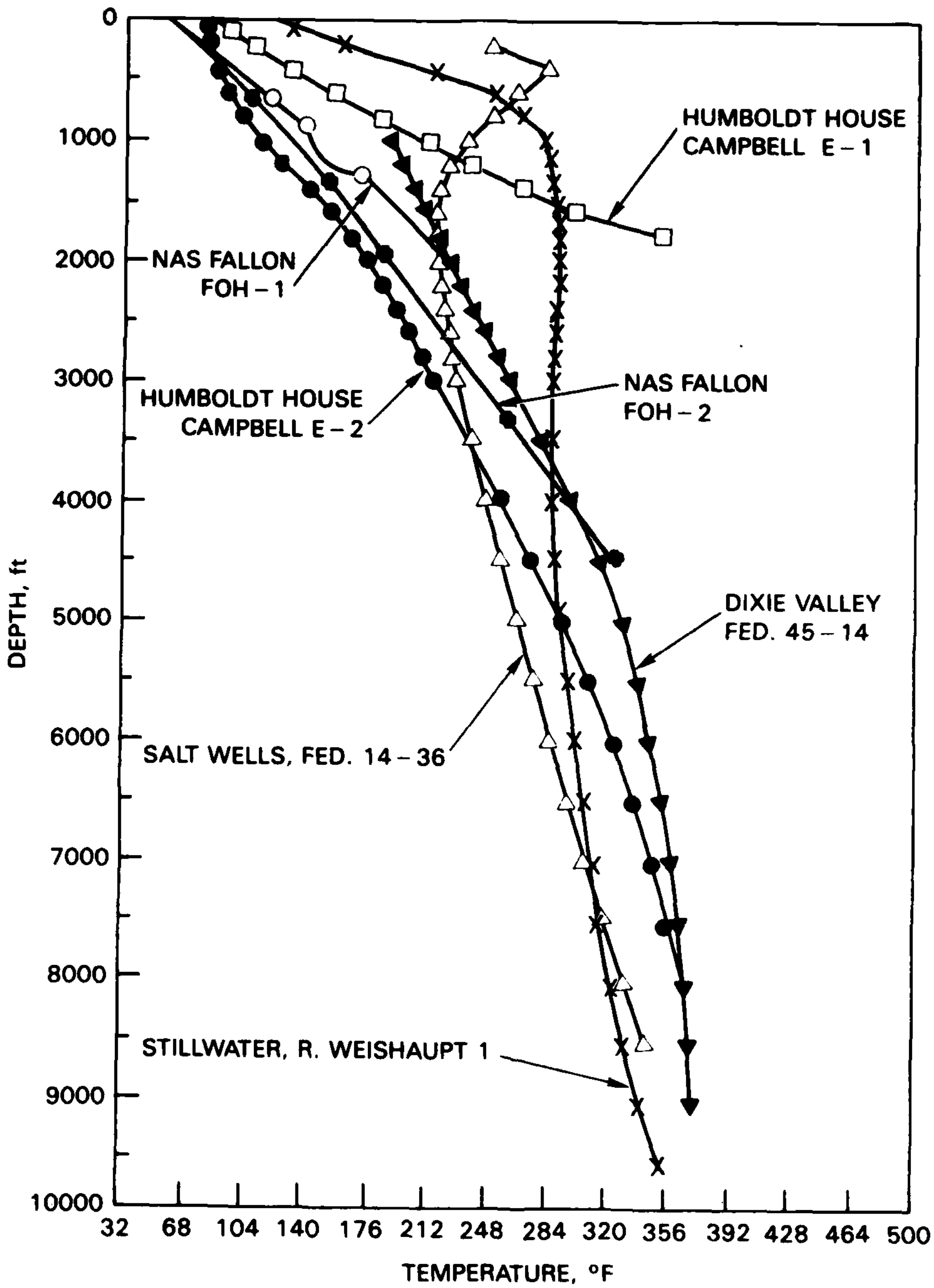


FIGURE 17. Temperature Profiles of FOH-1 and FOH-2 Plotted Against Temperature Profiles From Four Moderate-Temperature (302 to 392°F) Systems. Modified from Edmiston and Benoit (1984).

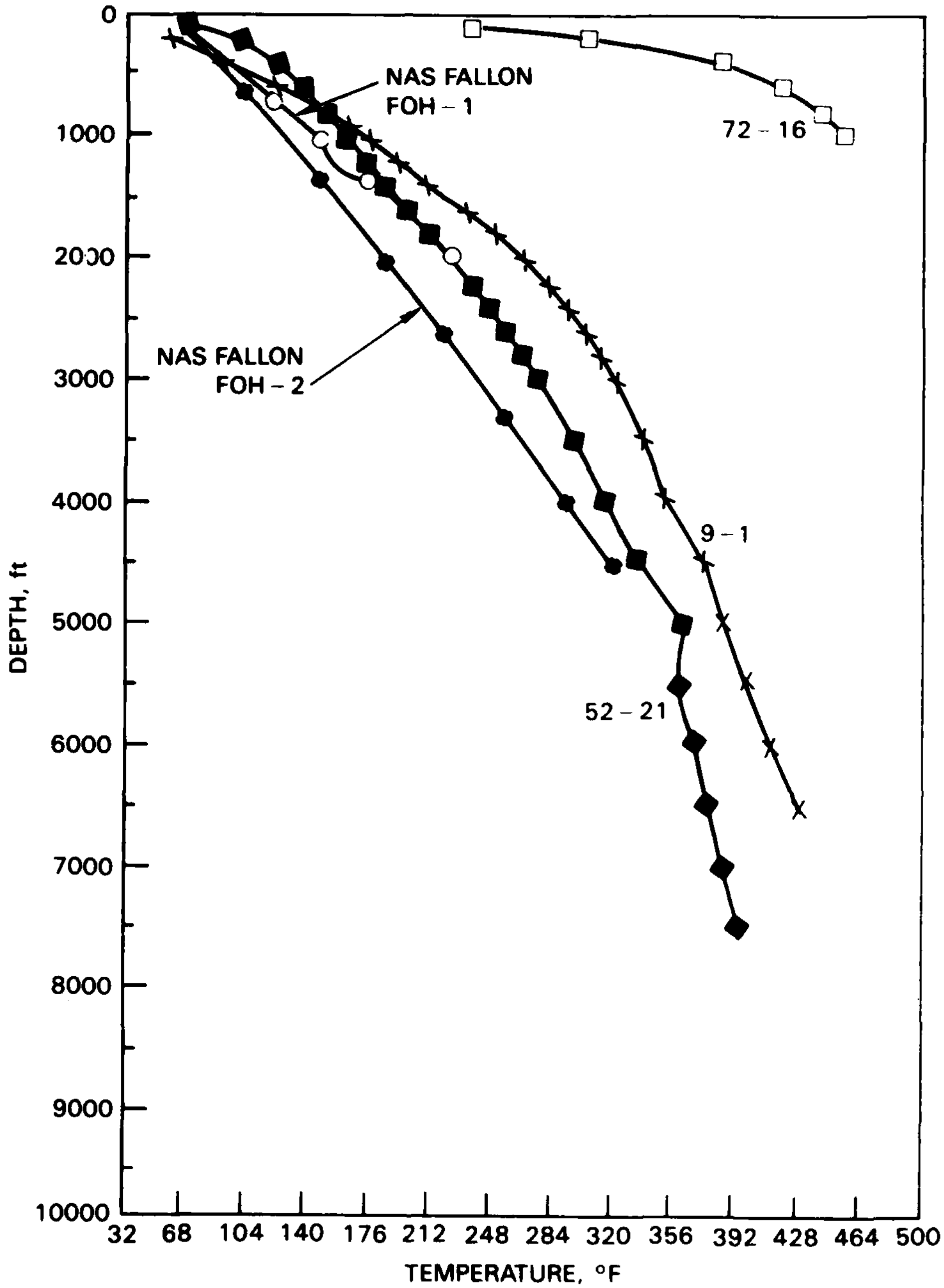


FIGURE 18. Temperature Profiles of FOH-1 and FOH-2 Plotted Against Temperature Profiles From the Roosevelt High-Temperature (>392°F) System. Modified from Edmiston and Benoit (1984).

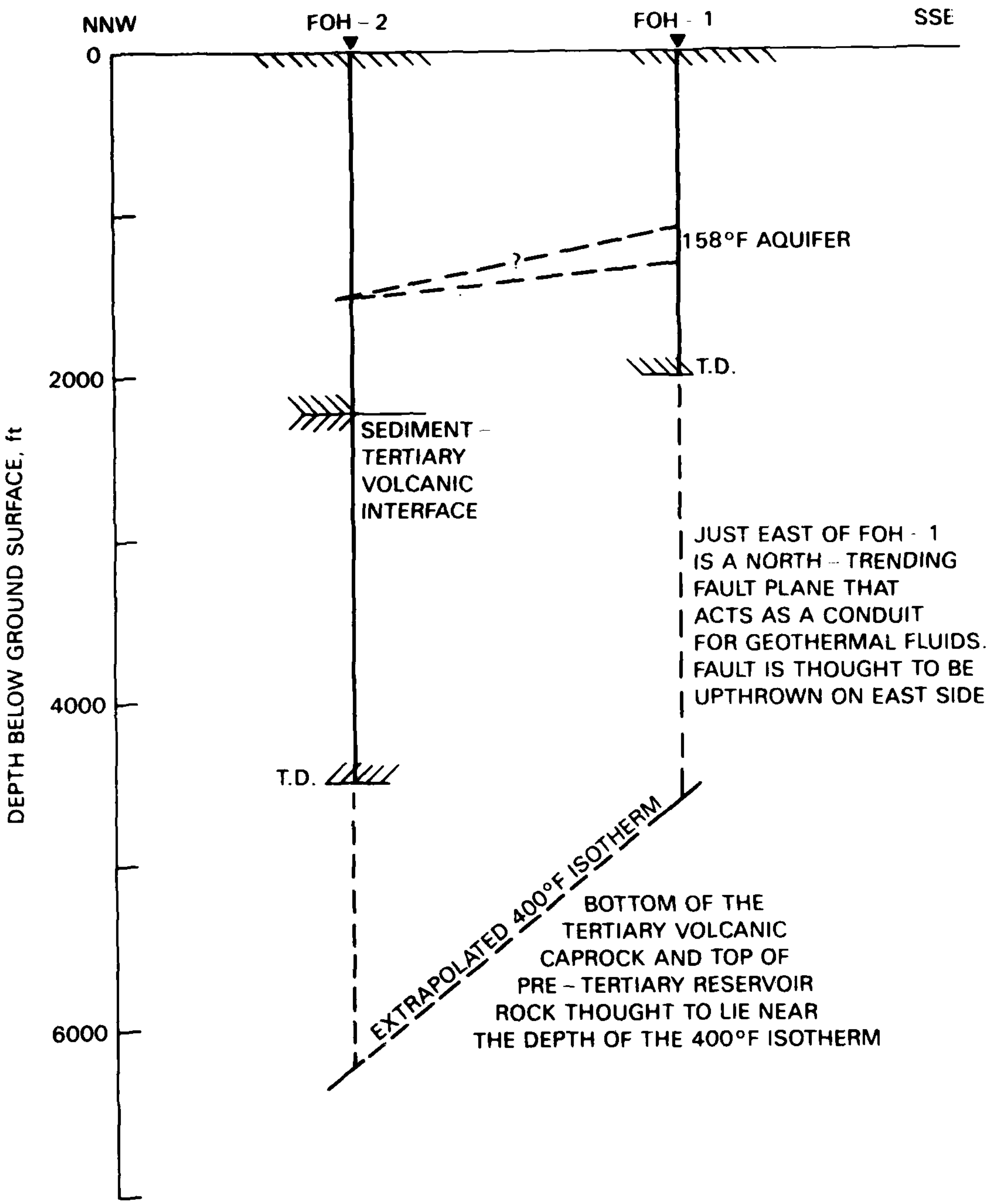


FIGURE 19. Depth of the Extrapolated 400°F Isotherm Below FOH-1 and FOH-2. Horizontal exaggeration is twice vertical. TD = total depth.

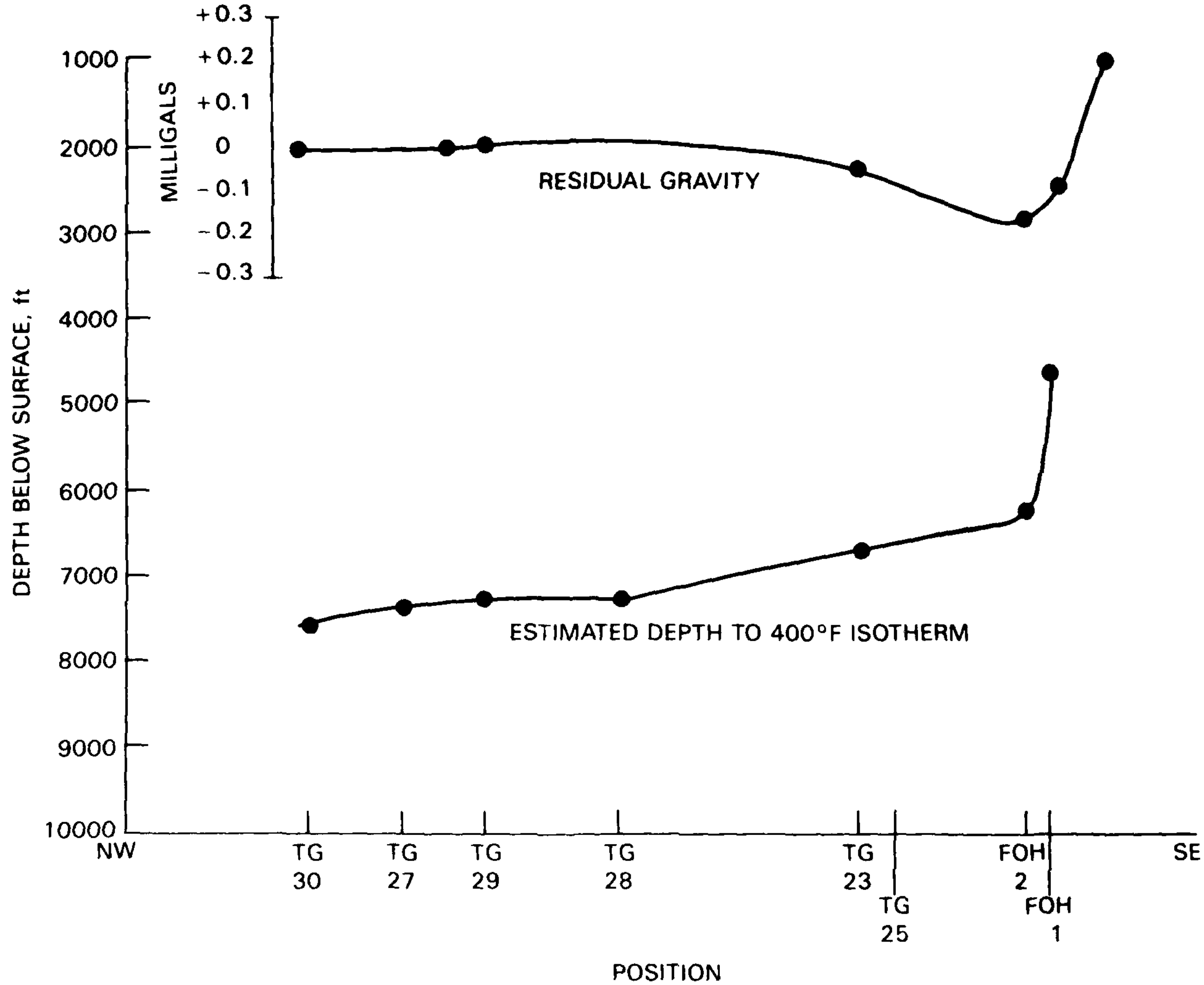


FIGURE 20. Isotherm Flattened Out to the North and West of FOH-1 and FOH-2. Note that the residual gravity contour mimics the 400°F isotherm contour. This cross section extends from the southeast corner to the northwest corner of Mainside.

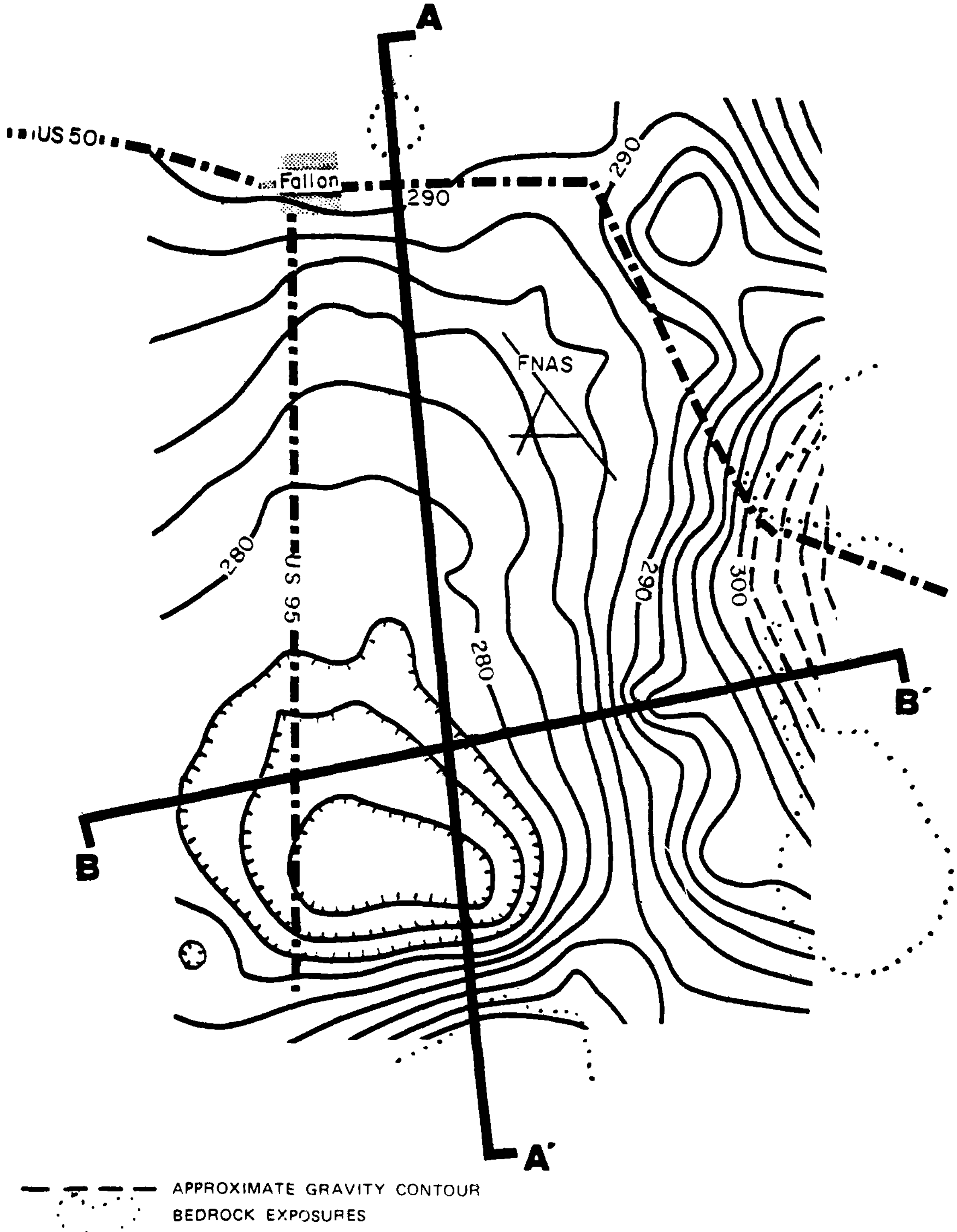


FIGURE 21. Terrain-Corrected Bouguer Gravity Map of the Southern Carson Sink (Carson Lake Area). Not corrected for regional gravity. Modified from Trexler and others (1979).

BIBLIOGRAPHY

Benoit, W. R., and R. W. Butler. "A Review of High-Temperature Geothermal Developments in the Northern Basin and Range Province," in *The Role of Heat in the Development of Energy and Mineral Resources in the Northern Basin and Range Province; Special Report No. 13*. Davis, Calif., Geothermal Resources Council, 1983.

Benoit, W. R., and others. *Discovery and Geology of the Desert Peak Geothermal Field: A Case History*, Nevada Bureau of Mines and Geology Bulletin 97, 1982. 82 pp.

Bruce, J. L. *Fallon Geothermal Exploration Project, Naval Air Station, Fallon Nevada*. Naval Weapons Center, China Lake, Calif., NWC, May 1980. (NWC TP 6194, publication UNCLASSIFIED.)

Burke, D. B., and E. H. McKee. "Mid-Cenozoic Volcano-Tectonic Troughs in Central Nevada," *Geological Society of America Bulletin*, Part I, Vol. 90, February 1979. Pp. 181-84.

California Department of Conservation Division of Oil and Gas. *Geothermal Hot Line*, S. R. Hodgson, ed. Sacramento, Calif. Dept. of Conservation, 1986. Vol. 16, No. 1 and 2. P. 22.

Cerini, D. J., C. P. Diddle, and W. C. Gonser. Project Development Desert Peak 9 MW Power Plant, in *Geothermal Energy: Bet on it!* Transactions, Volume 8, Geothermal Resources Council 1984 Annual Meeting, 26-29 August 1984, Reno, Nevada. Davis, Calif., Geothermal Resources Council, 1984. Pp. 32-39.

Cross, T. A., and R. H. Pilger, Jr. "Constraints on Absolute Plate Motion and Plate Interaction Inferred From Cenozoic Igneous Activity in the Western United States," *American Journal of Science*, Vol. 278, 1978. Pp. 865-902.

Davis, G. A. "Problems of Intraplate Extensional Tectonics, Western United States, With Special Emphasis on the Great Basin," presented at the Basin and Range Symposium and Great Basin Field Conference 1979, Las Vegas, Nev., October 1979.

Dickinson, W. R., and W. S. Snyder. "Geometry of Triple Junctions Related to San Andreas Transform," *Journal of Geophysical Research*, Vol. 84, 1979. Pp. 609-28.

Eardley, A. J. *Structural Geology of North America*. New York, Harper & Brothers, 1951.

Edmiston, R. C., and W. R. Benoit. "Characteristics of Basin and Range Geothermal System with Fluid Temperature of 150°C to 200°C," in *Geothermal Energy: Bet on it!* Transactions, Volume 8, Geothermal Resources Council 1984 Annual Meeting, 26-29 August 1984, Reno, Nevada. Davis, Calif., Geothermal Resources Council, 1984. Pp. 417-24.

Geothermal Resources Council. "On Location: State Scene California and Nevada," *Geothermal Resources Council Bulletin*, Davis, Calif., December 1985. Vol. 14, No. 11.

Gilbert, G. K., *U.S. Geography and Geology Surveys West 100th Meridian Progress Report*, 1872.

Grose, L. T., and G. V. Keller. "Geothermal Energy in the Basin and Range Province," presented at the Basin and Range Symposium and Great Basin Field Conference 1979, Las Vegas, Nev., October 1979.

Hastings, D. D. "Results of Exploratory Drilling Northern Fallon Basin, Western Nevada," presented at the Basin and Range Symposium and Great Basin Field Conference 1979, Las Vegas, Nev., October 1979.

Helioscience General Joint Venture. *Development of Geothermal Power NAS Fallon, Nevada, N62474-82-C-1035, Final Report*. New York, Helio Science Inc., October 1985.

Hill, D. G., and others. "Soda Lake, Nevada, Thermal Anomaly," in *Expanding the Geothermal Frontier*, Transactions Volume 3, Geothermal Resources Council Annual Meeting, 24-27 September 1979, Reno, Nevada. Davis, Calif., Geothermal Resources Council, 1984. Pp. 305-08.

Hunt, C. B. "The Great Basin, an Overview and Hypotheses of its Origin," presented at the Basin and Range Symposium and Great Basin Field Conference 1979, Las Vegas, Nev., October 1979.

Katzenstein, A. M., and K. J. Danti. *Evaluation of Geothermal Potential of the Naval Air Weapons Training Complex, Fallon, Nevada*. Naval Weapons Center, China Lake, Calif., NWC, April 1982. (NWC TP 6359, publication UNCLASSIFIED.)

Lageson, D. R. "Regional Tectonics of the Cordilleran Fold and Thrust Belt," presented at the 1982 AAPG Fall Education Conference, Montana State University, Bozeman, Montana, 1982.

Mitchell, A. H. G., and M. S. Garson. *Mineral Deposits and Global Tectonic Settings*. New York, Academic Press Inc., 1981.

Morrison, R. B. *Lake Lahontan: Geology of Southern Carson Desert, Nevada*. Washington, D.C., U.S. Government Printing Office, Geological Survey Professional Paper 401, 1963. 156 pp.

Naval Oceanography Command. U.S. Navy and Marine Corps Meteorological Station Climatic Summaries. Asheville, N.C., Naval Oceanography Command, October 1979.

Naval Weapons Center. *Programmatic Preliminary Environmental Assessment for the Fallon NAS Geothermal Development Program Fallon, Nevada*. NWC, China Lake, Calif., NWC, September 1981. (NWC AdPub 263, publication UNCLASSIFIED.)

Sass, J. H., and others. "Chapter 13: Heat Flow From the Crust of the United States," in *Physical Properties of Rocks and Minerals*, ed. by Y. S. Touloukian and others. New York, McGraw-Hill Book Company, 1981. Pp. 503-48.

Sprinkel, D. A. "Apparent Reverse Movement on Previous Thrust Faults Along the Eastern Margin of the Basin and Range Province, North-Central Utah," presented at the Basin and Range Symposium and Great Basin Field Conference 1979, Las Vegas, Nev., October 1979.

Stewart, J. H. *Geology of Nevada; A Discussion to Accompany the Geologic Map of Nevada.* Menlo Park, Calif., U.S. Geological Survey, Nevada Bureau of Mines and Geology Special Publication 4, 1980. 136 pp.

Stewart, J. H., and J. E. Carlson. *Cenozoic Rocks of Nevada* (Four Maps and Brief Description of Distribution, Lithology, Age, and Centers of Volcanism). Nevada Bureau of Mines and Geology, Map 52, 1976.

Trexler, D. T., and others. *Area Specific Geothermal Assessment, Nevada.* Contract No. DE-AC08-79NV10039. University of Nevada, Reno, 1979. Pp. 161-89.

Willden, R. "Late Tertiary Compressional Features in Churchill County, Nevada," *Geological Society of America,* Bulletin No. 80, 1969.

Willden, R., and R. C. Speed. "Geology and Mineral Deposits of Churchill County, Nevada," *Nevada Bureau of Mines and Geology,* Bulletin No. 83, 1974. 95 pp.

Yeamans, Jr., F. L. "Basin and Range Hydrology: An Empirical Approach," in *The Role of Heat in the Development of Energy and Mineral Resources in the Northern Basin and Range Province; Special Report No. 13.* Davis, Calif., Geothermal Resources Council, 1983.

Zoback, M. L., and G. A. Thompson. "Basin and Range Rifting in Northern Nevada: Clues from a Mid-Miocene Rift and its Subsequent Offsets," *Geology,* Vol. 6 (1978), pp. 111-16.

Appendix

FOH-2 NAS FALLON
JUNE 1986

LITHOLOGY LOG

I. DESCRIPTION OF CHIP SAMPLES

DEPTH, ft/ THICKNESS, ft*	
0/6	Surface alluvium.
6/14	Sand, lithic wacke - yellowish gray to pale yellowish brown, very poorly sorted, very coarse to very fine.
20/20	Clay with 35 to 40% sand - light greenish gray, calcareous with gumbo texture. Sand - same as above.
40/80	Clay and sand mix - bluish gray to greenish gray, very slight H_2S odor.
120/80	Sand, lithic to feldspathic wacke - medium to dark gray, well sorted, fining downward from very small gravel to medium fine sand.
200/140	Sand, lithic wacke with sparse interbedded clays (approx. 5 to 10%) - light gray color, predom. medium to coarse grained, subrounded.
340/80	Clay - greenish gray, with sparse interbedded sand (lithic wacke), sand fraction increasing to 60% of sample toward bottom of interval.
420/100	Clay - greenish gray, with up to 15% sand.
520/40	Sand, lithic to feldspathic wacke - light greenish gray, poorly sorted, very fine sand to fine gravel; very sparse small (<0.02 inch dia.) pyrite masses.
560/30	Clay and shale - light greenish gray; and sand, as above, is <5% of sample.

*Depth to top of unit, feet/thickness of unit.

590/10
Sand, as above - medium to fine grained.

600/20
Shale (65%) and sand, as above.

620/420
Sand and shale, as above - light greenish gray; shale percentage ranges from 15 to 75% (avg= 40%). Pyrite nodules ranging up to 0.012 inch dia.

1040/120
Clay - green to gray green, with moderate sand.

1160/160
Mixed sand, clay, and shale.

1320/240
Shale - dark green to black, with sparse to moderate interbedded sand.

1560/60
Shale - light grey to light green, with sparse interbedded coarse sand. Sand contains sparse angular basaltic fragments, 0.04 to 0.12 inch diameter and moderate accessory magnetite.

1620/40
Shale - light grey to light tan, with sparse to moderate lithic wacke sand lenses. Sand fraction ranges from coarse sand to fine pebbles (angular basalt and rounded to angular quartz and other lithic fragments).

1660/20
Sand, lithic wacke - average medium grain size with a range from very coarse to fine, angular to well rounded (including a clean, doubly-terminated quartz crystal). Moderate basalt fragments and sparse intermediate tuffaceous fragments, also feldspar, micas, olivine, and pyroxene. Sparse shale.

1680/20
Sand, as above, but with moderate to abundant tuffaceous fragments. Sparse shale.

1700/40
Sand, lithic wacke, as above, but coarse to very coarse, well mixed, angular to rounded.

1740/20
Sand, as last interval, but with 40% shale - light greenish grey.

1760/60
Shale - light greenish grey to light tan grey, with 25 to 30% sand, as above.

1820/20

Shale - light tan grey to light grey, with <10% (predominately) coarse sand, as above.

1840/40

Sand, lithic wacke, as above, with 35 to 50% shale.

1880/20

Same as last interval but with 60 to 70% shales.

1900/40

Sand, lithic wacke to quartz arenite - fine to coarse grained, with 20 to 30% shale and mudstone. Very sparse nodular pyrite.

1940/60

Mudstone - olive grey to tan grey, with 30 to 55% sand and water lain tuff. Very sparce nodular pyrite.

II. DESCRIPTION OF CORE SAMPLES

DEPTH, ft/
THICKNESS, ft

2000/42

Carbonaceous mudstone - olive gray, moderate layered carbonaceous material. Bedding inclined at 40 degrees to horizontal.

2042/1

Sandstone - olive gray, fine grained with sparse carbonaceous material. Bedding inclined at 20 degrees to horizontal.

2043/6

Claystone/mudstone - olive gray, sparse stringers of carbonaceous material (plants), very sparse gray, fine-grained pyrite concretions.

2049/67

Mudstone with interbedded sandstone - olive gray, carbonaceous, as above. Bedding inclined at 20 to 30 degrees to horizontal. Sandstone is a friable lithic wacke to arenite and ranges in size from fine sand to pebble.

2116/76

Sandstone, as above - light olive gray, predominately medium to coarse grained but moderately to poorly sorted. Sparse to moderate mud clasts and mud and silt interbeds throughout. Pyrite nodules in mudstone at 2161 to 2164 feet.

2192/31

Mudstone with sand stringers (<5 inches thick) - olive gray with sparse carbon.

2223/50

Basalt - vesicular, dark gray to olive black, fine-grained, altered *. Sparse fracturing thoughout, brecciated over 28% of this interval. Vugs and fractures filled with clay (baked), quartz, opal, and pyrite. Abundant disseminated pyrite at 2275 to 2281 feet.

(* Nearly all of the volcanic section in this hole is altered by heat and fluids, but much of the alteration is only apparent in thin section. Therefore, whenever alteration is noted in the log, it refers to macroscopic alteration unless otherwise noted.)

2283/14

Basalt - dense, dark gray, sparse opal and pyrite filled fractures.

2297/49

Basalt - vesicular with vugs filled as above, dark gray to olive black. Brecciated over 37% of this interval.

2346/7

Basalt, as above but dark reddish gray.

2353/9.5

Sand - lithic to feldspathic wacke, fine to very fine grained, friable, 9 feet lost.

2362.5/68.5

Basalt - vesicular, dark gray to dark reddish gray, sparse to very abundant vugs. Vugs open and coated or filled with opal and light bluish gray clay. Brecciated at 2396 to 2399 and 2409 to 2413 feet.

2431/8

Basalt - blackish red to very dark red, vesicular with opal, mud, and pyrite. Rock in this interval is very broken and has a "burnt" look to it. 60% of interval lost.

2439/26

Basalt - medium gray to very dusky red purple, vesicular with vugs small to medium size, moderate to very abundant, primarily filled with opal and clay with sparse calcite. Sparse fracturing throughout, brecciated at 2444 to 2452 feet - 88% lost.

2465/76.5

Basalt, as above, with several brecciated and lost core zones (12% brecciated, 5% lost):

2465: (1 ft), 0.5 ft lost
2472: (3 ft), 1.5 ft lost
2492: (4 ft), 2 ft lost
2512: (0.5 ft), no loss.

Also several older fracture/breccia zones with opal, pyrite and clay fracture fillings:

2476: (3 ft)	2483: (2 ft)	2489: (3 ft)
2496: (4 ft)	2513: (4.5 ft)	2525: (12 ft)

2541.5

Discordant contact - fault displacement plane at approximately 50 degrees to assumed horizontal.

2541.5/0.8

Water laden volcanic ash with sparse sand - light olive gray to moderate olive brown.

2542.3/0.7

Mudstone - olive gray.

2543/6.7

Basalt, as above - very vesiculated, with opal and calcite fillings.

2549.7/1.3

Ash (?) with sand, as above - with 0.2 ft mudstone lens. Upper contact not recovered.

2551/2

Mudstone, as above.

2553/5

Basalt, as above but well altered, easily broken, vesicular, with opal and calcite coatings and fillings.

2558/6

Basalt - sparse to moderate vesiculation, predominately filled with opal, quartz, clay, and calcite (in that order), with fractures (sparse) filled with calcite.

2564/27

Basalt - vesiculated, blackish red to dusky brown to very dusky purple. 63% brecciated, bluish green color with "baked" mylonite and clay fracture filling. Vug fillings of calcite, opal, clay, quartz, and very, very sparse pyrite.

2591/6

Basalt, as interval 2558. Competant, sparse to moderate vesiculation with vug and fracture filling as above; calcite deposition is the most recent.

2597/12

Basalt - well brecciated and altered ("baked"), blackish red/dusky brown to bluish green.

2609/6
Basalt, as interval 2591. Competent but vugs are without opal fillings.

2615/13
Basalt, as interval 2597.

2628/20
Basalt - vesiculated, blackish red to very dusky red purple. Brecciated but well cemented with quartz and calcite.

2648/10
Basalt - brecciated and altered, as interval 2597.

2658/23
Basalt, as interval 2628.

2681/28
Rhyolite (?) - very dark red to dark reddish brown, brecciated with quartz cement. Freshly broken at 2696.5 (2.5 ft).

2709/17
Basalt - dark gray to black, dense, fine grained. Finely fractured, with fractures cemented with quartz and calcite.

2726/15
Basalt - dark red to dark gray. Brecciated.

2741/66
Basalt, as interval 2709.

2807/13
Basalt (rhyolitic?) - dusky brown to very dusky red (moderate reddish brown transcending to dark gray at 2813 ft). Well brecciated but solid. Cemented with mylonite, quartz and calcite.

2820/19
Basalt, as interval 2709 but more vesicular. Moderate to abundant, small to very small vesicles filled with grayish green clay.

2839/2.5
Basalt, as interval 2807.

2841.5/13.5
Basalt, as interval 2820 but with vugs and fractures filled primarily with calcite and clay. (Later fracturing?).

2855/11
Basalt, as interval 2807 (rhyolitic?).

2866/19

Basalt, as interval 2841.5. As above, calcite and quartz fracture fillings are later than the brecciation with mylonite "cement".

2885/127

Basalt, as interval 2807; rhyolitic over much of section. Some sections show scoriaceous flow characteristics, in others, such as 2890, it may be a rhyolite tuff. Color is moderate reddish brown though very dusky red to dark gray. Overall the rock is fairly competent to competent but brecciated with fragments ranging to very large. At 2924 calcite and quartz veins are broken in the breccia, while at 2997 (5 ft) they fill fractures cutting across the brecciation.

3012/3

Breccia zone in basalt, as above, with very abundant calcite and quartz filling and cement. Rock fragments are mixed rhyolitic at the top of the interval to dark gray basaltic on the bottom.

3015/57

Basalt - dark gray to dusky yellowish brown; fine grained with plagioclase phenocrysts; fractured and cemented with calcite and quartz. Fractured, with mylonite in fractures with quartz at 3049 (22 ft). Breccia zone without quartz or calcite at 3034 (3 ft).

Thin section at 3032 ft shows a well altered groundmass of dark brown and most of the small plagioclase laths as remnant ghosts. The larger phenocrysts appear relatively untouched.

Thin section at 3043 ft shows a fairly fresh groundmass of plagioclase laths with moderate subanhedral to anhedral olivine, a tracytic texture.

3071/2

Breccia zone in basalt - olive to bluish green to dusky red.

3073/31

Basalt - very dusky red to reddish black, fine grained. Broken over 29% of the interval. Thin section shows plagioclase phenocrysts and opal and quartz amygdules from sparse vesicles.

3104/2

Basalt, as above - dark reddish brown.

3106/18

Muddy conglomeratic lithic wacke - grayish. Predominately volcanic rock fragments.

Thin section at 117 ft shows an altered mud or clay

matrix surrounding rounded fragments of tholeiitic (?) basalt as well as smaller fragments of plagioclase, olivine (?), quartz, and opaques and subhedral opaques.

3124/17

Rhyolite tuff (?) - dark reddish brown, incorporates abundant to very abundant fragments of other volcanics. Fragments in this interval tend to be angular and blocky.

3141/87

Basalt - dark gray, fine to medium grained, well fractured with no predominate angle. Primarily only myloite in fractures with very sparse calcite and quartz. Brecciated over 30% of the interval:

3163 (5 ft)	3179 (9 ft)
3208 (5 ft)	3221 (7 ft)

1.5 inch fracture filling at 3204 ft; dipping at 40 degrees to assumed horizontal; matrix light to medium gray with basaltic and rhyolitic fragments. Thin section of this material shows a dark brown matrix with ghost plagioclase laths, and calcite amygdules surrounding fragments of tholeiitic basalt and large subhedral pyroxene (?) crystals.

3228/19

Basalt (rhyolitic ?), as interval 3124 - moderate to dark reddish brown. A mixture of textures: medium to fine grained dense, fine grained vesicular (with and without flow patterns and "stretched" vugs), vugs filled with black to blueish green clay. Fragments in this interval tend to be smooth and rounded.

3247/17

Rhyolitic basalt as above, but more vesicular. Thin section at 3250 ft shows a totally altered groundmass with small plag. laths in matrix with reaction rims and as ghosts; larger plag. phenocrysts show little alteration.

3264/178

Basalt - medium/dark gray to very dusky red purple with sparse very dusky red. Fine grained dense to vesicular. Very competent interval, overall; moderate, fine fractures with quartz and calcite. Vesiculated intervals: 3270 (4 ft) 3331 (13 ft) 3367 (13 ft) 3386 (14 ft)

3442/49

Basalt - greenish black to greenish gray, dense fine grained. High-angle to near-vertical fracturing up to 1.5 inches wide and filled with mylonite and calcite (sparse dog tooth crystals) from 3451 to 3495 feet. In thin section plagioclase phenocrysts and sparse to moderate euhedral pyrite are apparent.

3491/25

Welded tuff with basalt - dark olive green to dusky red purple; tuff with sand grains; basalt is fine to medium fine grained with plagioclase phenocrysts.

Thin section of 3505 ft shows most of the sample as an altered, dark brown matrix with sparse to moderate plagioclase and very sparse pyroxene phenocrysts.

3517/207

Basalt - predominately very dusky purple to dark gray to brownish black. Interval alternates vesiculated, very dusky purple units and dense, dark gray to brownish black units. Each pair represents a single flow unit. The contact between two units at 3564 feet is very distinct, while the others do not exhibit such a clear boundary.

VESICULAR		DENSE
3517 (18 ft)	---	3535 (29 ft)
3564 (14 ft)	---	3578 (5 ft)
3583 (12 feet total - no clear transition is apparent)		
3595 (13 ft)	---	3608 (17 ft)
3625 (6 ft)	---	3631 (10 ft)
3641 (13 ft)	---	3654 (15 ft)
3669 (23 ft)	---	3692 (10 ft)
3702 (22 feet total - no clear transition is apparent)		

In addition, several of the units (primarily the vesiculated sections) exhibit moderate to severe hydrothermal alteration, primarily of a physical nature as seen macroscopically. The units appear "baked" and the vesiculated sections are also "crumbly" in texture: 3539 (5 ft) 3564 (19 ft) 3625 (7 ft) 3674 (7 ft)

Thin section of sample at 3621 ft shows a fresh basalt, very little alteration, groundmass composed of plagioclase laths and moderate to abundant pyroxene and olivine with moderate to abundant opaque infilling; very sparse hornblende (?) phenocrysts.

Thin section of sample at 3626 ft shows a basalt, well altered; fine grained matrix and small plagioclase laths are eroded or completely gone; larger plagioclase laths are eroded around the edges and some show a slight sieve structure; very sparse small pyroxenes mostly altered to clays.

3724/144

Basalt - vesicular, very dusky reddish purple to dusky red, fine to medium fine grained with plagioclase phenocrysts, vugs predominately clay filled (blue green to black), sparse calcite, very sparse quartz.

3868/0.4

Clay - very dusky red.

3868.4/31.6

Basalt - dark gray to very dusky reddish purple, fine grained, sparse to no vesiculation. Highly fractured and broken, with mylonite and very sparse calcite at 3879 (21 ft).

3900/22

Basalt - very dusky reddish purple, vesiculated, with clay vug filling. Fractured and broken with mylonite and very sparse calcite at 3905 (4 ft (3 ft lost)) and 3911 (5 ft).

3922/7

Basalt - as interval above but severely "cooked" (altered); 3 feet lost. Color is very dusky red to moderate reddish brown; clays are light blue and gray to grayish green with sparse small pyrite crystals.

3929/7

Welded tuff - very light gray to light bluish gray.

3936/34

Basalt - fine grained vesicular (sparse to abundant vugs with clay filling), very dusky reddish purple to reddish brown. Moderately fractured with mylonite and calcite filling at 3955 (15 ft).

3970/14

Welded tuff (rhyolitic) - lithic fragments over 0.4 inch diameter, also smaller quartz and plagioclase fragments and pyroxene, plagioclase, and opaque crystals, moderate reddish brown to medium gray and reddish gray. Very broken at 3976 (3 ft) and 3984 (5 ft).

3984/16

Basalt - reddish black, vesicular with clay vug filling. Interval brecciated with calcite and mylonite filling and cement.

4000/14

Basalt - blackish red to dark reddish brown, vesicular with black clay vug filling.

4014/96

Basalt - blackish very dusky reddish purple, fine to medium fine grained, vesicular, some sections exhibit flow banding, vugs with clay and very sparse opal or quartz. Fractured over much of section with clay (mylonite), calcite, and quartz filling and very fine disseminated pyrite.

4110/8

Basalt - fine grained, dense, black.

4118/68

Basalt, as interval 4014; broken at 4146 (11 ft); abundant vesiculation at 4157 (29 ft).

4186/13

Andesite (?) - medium fine grained, greenish black, massive, very sparse vesiculation with clay and calcite filling.

4199/25

Basalt - dusky red to purplish black, medium grained, vesicular with clay and calcite. Highly altered at 4204 (10 ft), 9 feet lost, sparse vugs with minute doubly terminated quartz grains, interval shows moderate finely disseminated pyrite.

4224/87

Basalt - purplish black mottled with dark bluish green and rust color, medium-fine grained, vesicular, sparse to abundant disseminated pyrite. Fine fractures filled with calcite. Zeolite (?) at 4287.

4311/11

Basalt - dark gray to black, fine grained, massive, moderate vesiculation with calcite and clay vug filling.

4322/32

Basalt - dusky reddish purple to bluish green, abundant vesiculation with blue green clay, high degree of alteration at 4343 (4 ft).

4354/27

Basalt - as above, but showing finer and more sparse vesiculation, more massive. Fractured, with clay fracture filling.

4381/23

Basalt, as interval 4322.

4404/31

Basalt, as interval 4354.

4435/27

Basalt - purplish gray, moderate to abundant vesiculation with clay, calcite, and pyrite in the vugs. Finely disseminated pyrite also occurs throughout this interval.

4465/23

Basalt - purplish black to dark gray green, fine grained dense with fine disseminated pyrite.

4488 - Total Depth.

INITIAL DISTRIBUTION

2 Chief of Naval Operations
  OP-413F (1)
  OP-45 (1)
2 Director of Navy Laboratories (DNL)
  DNL-05 (1)
  DNL-08E (1)
8 Naval Facilities Engineering Command, Alexandria
  FAC-03 (1)
  FAC-032E (1)
  FAC-04 (1)
  FAC-08T (1)
  FAC-09B (1)
  FAC-111 (1)
  FAC-111B (1)
  FAC-1113 (1)
1 Naval Facilities Engineering Command, Atlantic Division, Norfolk (Utilities Division)
1 Naval Facilities Engineering Command, Northern Division, Philadelphia (Utilities Division)
1 Naval Facilities Engineering Command, Pacific Division, Pearl Harbor (Utilities Division)
1 Naval Facilities Engineering Command, Southern Division, Charleston (Utilities Division)
5 Naval Facilities Engineering Command, Western Division, San Bruno
  Code 09B (1)
  Code 09C3 (1)
  Code 11 (1)
  Code 1112 (1)
  Code 24 (1)
4 Naval Sea Systems Command
  SEA-05H7 (1)
  SEA-070C (1)
  SEA-09B312 (2)
2 Space and Naval Warfare Systems Command
1 Commander in Chief, U.S. Pacific Fleet, Pearl Harbor (Code 325)
1 Headquarters, U.S. Marine Corps (LFF-2)
3 Naval Academy, Annapolis
  Director of Research (2)
  Library (1)
5 Naval Civil Engineering Laboratory, Port Hueneme
  Commanding Officer (1)
  L70 (1)
  L70PM (1)
  L72, D. Holmes (1)
  Technical Library (1)